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Cover: The cover photograph shows three male river otters (*Lontra canadensis*) just after they have left the release cage. This was part of a project to restore otters to Indiana. The picture was taken in January 1996 at an otter release at Old Timbers Lake on Big Oaks National Wildlife Refuge in Ripley County, Indiana. See related article on page 71. (Photo by Richard Fields of the Dept. of Natural Resources)

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MUDCRACKS, BIRD'S-EYE, AND ANHYDRITE IN INTERTIDAL/SUPRATIDAL LATE SILURIAN KOKOMO LIMESTONE, INDIANA

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ABSTRACT. The Kokomo Limestone Member of the Wabash Formation is of late Silurian age. This member consists of about 30 m of thinly-laminated carbonates in the Logansport area of north-central Indiana. The almost complete lack of fossils throughout the member indicates a hypersaline depositional environment. Previous workers interpreted the Kokomo Limestone as a product of an intertidal and subtidal environment, or reported the presence of syneresis cracks to argue for a restricted lagoon and intertidal environment. In this paper we show that desiccation mudcracks, storm-produced intraclasts, intraformational conglomerate, and bird's-eye structures taken together indicate an intertidal and supratidal environment during deposition of the Kokomo Limestone. Microscopic supporting evidence includes microcracks, intraformational micro-breccia/conglomerate, an abundance of dolomite, anhydrite/gypsum pseudomorphs, and fenestrate structures lined with calcite, dolomite and tar. Couplets of dark and light laminae were previously interpreted as annual cycles, but we interpret them as daily tidal cycles, bimonthly spring tide deposits, and occasional storm tide deposits. We also show evidence of unconformities both at the base and at the top of the Kokomo Limestone Member.

Keywords: Mudcracks, bird's-eye, carbonates, intertidal, supratidal

The Kokomo Limestone Member of the Wabash Formation, Salina Group, is of late Silurian age, latest Ludlovian to early Pridolian (middle Cayugan) (Shaver et al. 1986). The contact with the underlying Mississinewa Shale is sharp and disconformable (Cummings & Shock 1928), but Pinsak & Shaver (1964) report lacking proofs for either disconformity or conformity. The upper contact with the Kenneth Limestone is sharp but poorly understood. According to Shaver et al. (1986), sand grains and other clastic sediments associated with this contact are not evidence of intra-Silurian unconformity but rather of pre-Middle Devonian karst. Pinsak and Shaver (1964) correlate the Kokomo Limestone to the A-2 unit of the Salina Formation of Michigan. The Kokomo Limestone is exposed in several quarries in the Logansport area of north-central Indiana. Thinly-laminated beds of the Kokomo Limestone are alternating light and dark layers less than 1 mm thick. Outcrop exposures also reveal stacking of small scale (2–5 cm) and large scale (30–100 cm) light and dark beds.

Even though most of the unit is dolomite, as noted by previous workers (Pinsak & Shaver 1964; Tollefson 1979; Nellist 1986), the Kokomo Member is still formally called a limestone rather than a dolomite. In this paper we adopt Nellist's (1986) subdivision of the Kokomo Limestone Member into the Morgan Hill Bed (Tollefson's beds A and B) and the Eel Bed (Tollefson's beds C, D, E and F). Tollefson (1979) considered the Kokomo Limestone depositional environment as a restricted, hypersaline intertidal environment on the isolated Wabash platform, which near the end of deposition changed into a more normal marine subtidal environment. Nellist (1986), however, interpreted the Kokomo Limestone depositional environment as a subtidal, restricted lagoon that near the end of deposition became shallower and, in parts, intertidal. Tollefson (1979) used the presence of broken and distorted laminae in the Morgan Hill Bed of the Kokomo Limestone as evidence of desiccation and subaerial exposure indicating presence of mudcracks, but Nellist (1986) interpreted the same features as subaqueous syneresis cracks and considered the lamination couplets to be of seasonal character. In this paper we demonstrate the presence of desiccation mudcracks not only in the outcrop, but also in thin

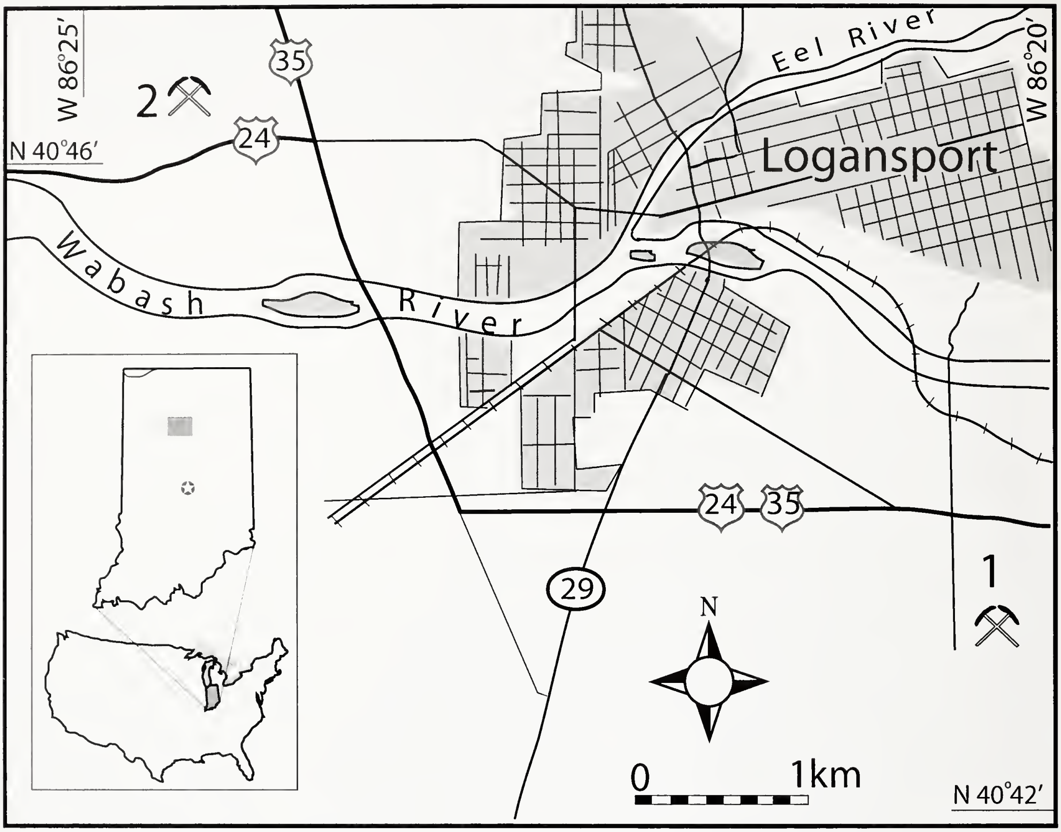

Figure 1.—Location of two quarries studied in Logansport, Indiana. The first is active Engineering Aggregates Quarry #1, and the second is now closed Engineering Aggregate Quarry #2, as referred to in the text. Drawing is based on USGS 7.5 minute series Topographic maps of Logansport, Lucerne, and Anoka Quadrangles.

sections. We argue in favor of an intertidal environment during the deposition of the Morgan Hill Bed of the Kokomo Limestone. The Eel Bed of the Kokomo Limestone contains sedimentary structures that include bird's-eye (fenestrate) structures, algal mats, gypsum/anhydrite blebs and pseudomorphs, penecontemporaneous dolomite, and intraformational storm tide deposits, that we interpret as indicative of a supratidal (Shinn 1983; Hardie & Shinn 1986) depositional environment. On a broader scale our research implies: 1) reinterpretation of Late Silurian paleotopography between the Michigan and Illinois basins, indicating partial exposure of the Wabash Platform during deposition of the Kokomo Limestone and before deposition of the Kenneth Limestone; and 2) the rejection of the subtidal syneresis hypothesis of crack formation in these carbonate sediments.

Location of the study area.—Our field work included study of two quarries in the Logansport area of north-central Indiana. Engineering Aggregates Quarry #2, now inactive, is located about 3 km west of Logansport, north of Indiana Highway 24 in E ½ of Sec. 28, T 27 N, R 1 E (Fig. 1). This quarry has been referred to as "Big Blue Hole Quarry" (Cummings & Shrock 1928) or as "Cass County Quarry" (Tollefson 1979). The uppermost part of the Morgan Hill Bed and the entire Eel Bed were studied in this quarry. Engineering Aggregates Quarry #1 is located south of town about 0.8 km south of Indiana Highway 35 in N ½ of Sec. 6, T 26 N, R 2 E. Tollefson (1979) refered to this quarry as the "South Logansport Quarry" and at the time of her work the lower part of the Morgan Hill Bed (her Unit A) was not exposed. After Nellist's (1986) study of the Kokomo Limestone in this quarry, about 5 m of the basal part of the Morgan Hill Bed was exposed. There were 52 samples of Kokomo Limestone collected and cut into thin sections for petrographic study.

SHRINKAGE CRACKS

Plummer and Gostin (1981) studied many examples of mudcracks and synaeresis cracks from the rock record and in laboratory experiments and concluded that no single feature of any shrinkage crack is useful in differentiating between the two. Evaporation of water from muddy sediment causes drying, shrinking and mudcrack formation. Shinn (1983) noted that no single sedimentary structure is more indicative of the upper intertidal and the supratidal depositional environment than mudcracks caused by shrinkage of carbonate mud. Desiccation mudcracks are generally continuous, polygonal, and often of several generations with V or U-shaped cross sections that are infilled from above. However, where desiccation has insufficient time to fully develop, an incomplete mudcrack system can form consisting of short but often intersecting cracks. Other sedimentary structures indicative of subaerial exposure and associated with desiccation mudcracks include raindrop imprints, evaporite casts, vertebrate tracks, bubbles and foam impressions (Plummer & Gostin 1981).

Syneresis cracks can form by expulsion of water from clays due to variations in water salinity at the sediment-water interface, but a majority of them are produced by compaction of clays substratally and are often associated with load structures (Plummer & Gostin 1981). Syneresis cracks are generally discontinuous, spindle, or sinuous in shape and of one generations only, with V or U-shaped cross-sections that are infilled either from above or from below (Plummer & Gostin 1981). Experiments with salinity changes (Burst 1965) produced small syneresis cracks but did not cause sediment injection. Pratt (1988) argued against deep burial and compaction and suggested dewatering of argillaceous sediment by ground motion from strong synsedimentary earthquakes as a mechanism for syneresis cracks formation. The rarity of syneresis cracks in Phanerozoic marine rocks is a consequence of greater content of organic matter in the sediment and organic binding of clay flocks in the water (Pratt 1988). Even some of the most widely cited examples of syneresis cracks from lacustrine rocks, like those of the Devonian Orcadian Basin of Scotland (Donovan & Foster 1972; Barclay et al. 1993), have recently been reinterpreted as subaerial mudcracks (Astin & Rogers 1991, 1993).

SHRINKAGE CRACKS IN THE KOKOMO LIMESTONE

We started our analysis with the older part of the Kokomo Limestone, hereinafter referred to as the Morgan Hill Bed (Nellist 1986), which is exposed in Engineering Aggregates Quarry #1, south of Logansport. The Morgan Hill Bed is a dark gray thinly-laminated dolomite that appears in small scale (2–5 cm) lighter and darker bands. The rock weathers into thin, platy chips that approximately follow the width of the colored bands. Frequently, weathering and breaking occurs along algal mat surfaces in the rock. About 3 m above the base of the Morgan Hill Bed (bottom bench in the quarry) there is a brecciated layer with disrupted lamination and numerous shrinkage cracks. Two samples (Figs. 2, 3) from that horizon were examined for this paper. Figure 2 shows deformed and broken laminae that are bent downward into a V-shape. Fracturing that affects one or two lamina couplets extends vertically 1–3 cm. Lateral spacing of cracks in some couplets is short (1 cm or less) while other couplets break in longer intervals (4 cm). Almost always, breakage starts in the dark lamina and disrupts the underlying one or two laminae. Rotation and displacement of broken parts of some laminae are evident. Overlying laminae increase in thickness in places where underlying laminae were broken. Breaking of overlying lamina occurs at places not coinciding with underlying cracks. In places where cracks were not filled with overlying laminae we saw pyrite or calcite secondary fills.

Another example (Fig. 3) showed a V-shape crack about 1 cm long in cross section. After we dislodged the rock and split it along the bedding plane, four five-sided shrinkage polygons (Fig. 4) with 3–8 cm long sides were exposed. The polygon edges are about 1 cm wide and contain calcite specks. The vertical extent of the polygon edges was about 1 cm. The bedding plane surface contains raindrop imprints. This hand sample contained three

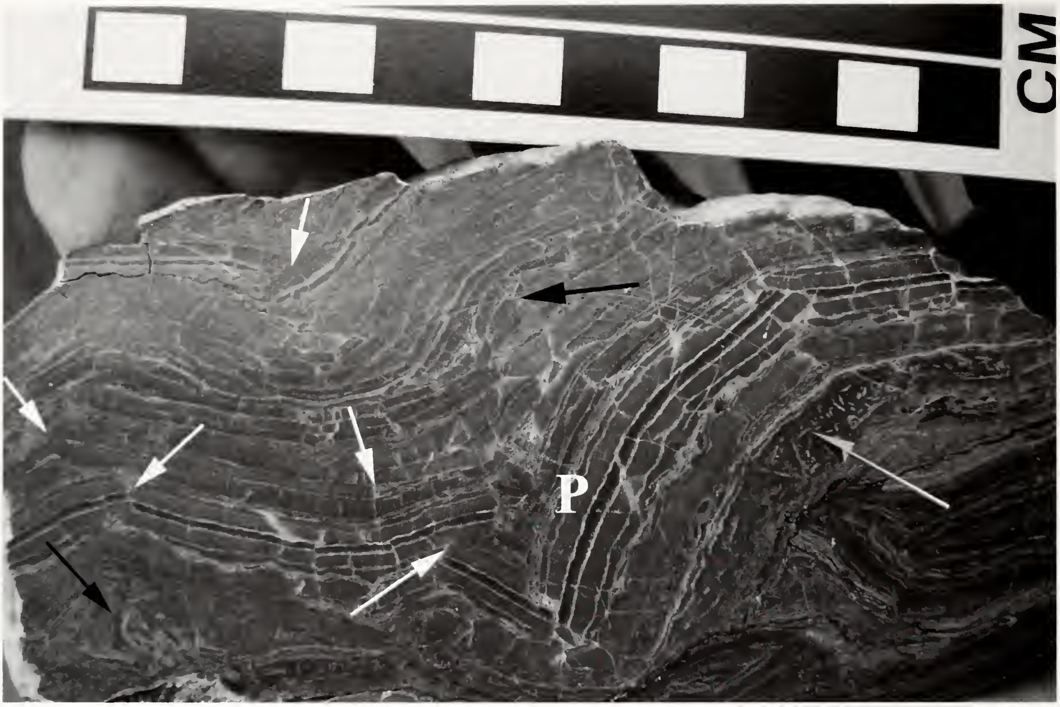

Figure 2.—Cut and polished sample of broken laminae 3 m above the base of Morgan Hill Bed. Broken and rotated chips of laminae are visible around black arrows. Multiple generations of cracks (white arrows) do not occur along the same vertical profile. Calcite and pyrite (P) are found in the center of large crack. Anhydrite/gypsum laths are visible around gray arrow.

sets of shrinkage cracks that were independently formed because their pattern did not match vertically (Fig. 4).

At the lower bench of the quarry we examined the middle and the upper part of the Morgan Hill Bed. Numerous surfaces showed a similar pattern of shrinkage cracks with five and four sided polygons having sides ranging from 5–15 cm. A sample collected from quarry ledge 9, about 8 m above the base of the

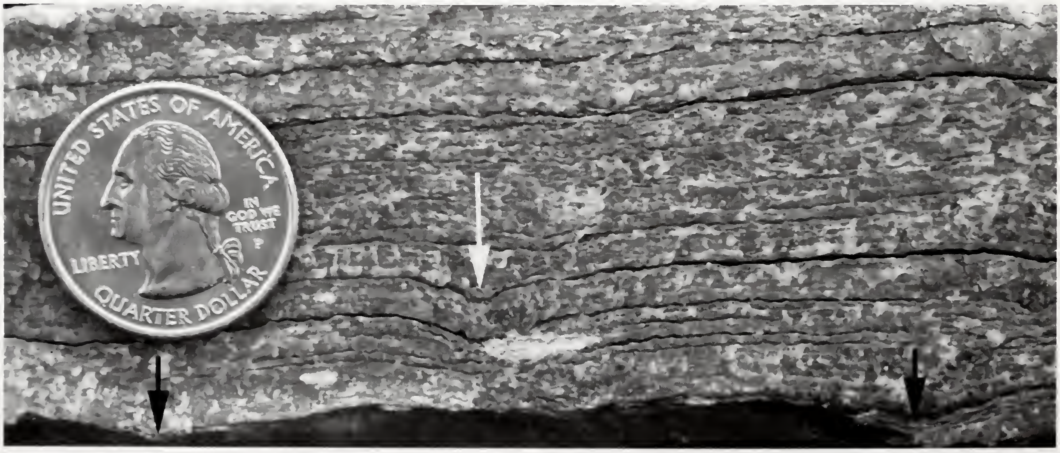

Figure 3.—Side view shows V-shaped crack in the lower center (white arrow). Black arrows point to a lower set of polygonal cracks. Coin diameter is 2.5 cm.

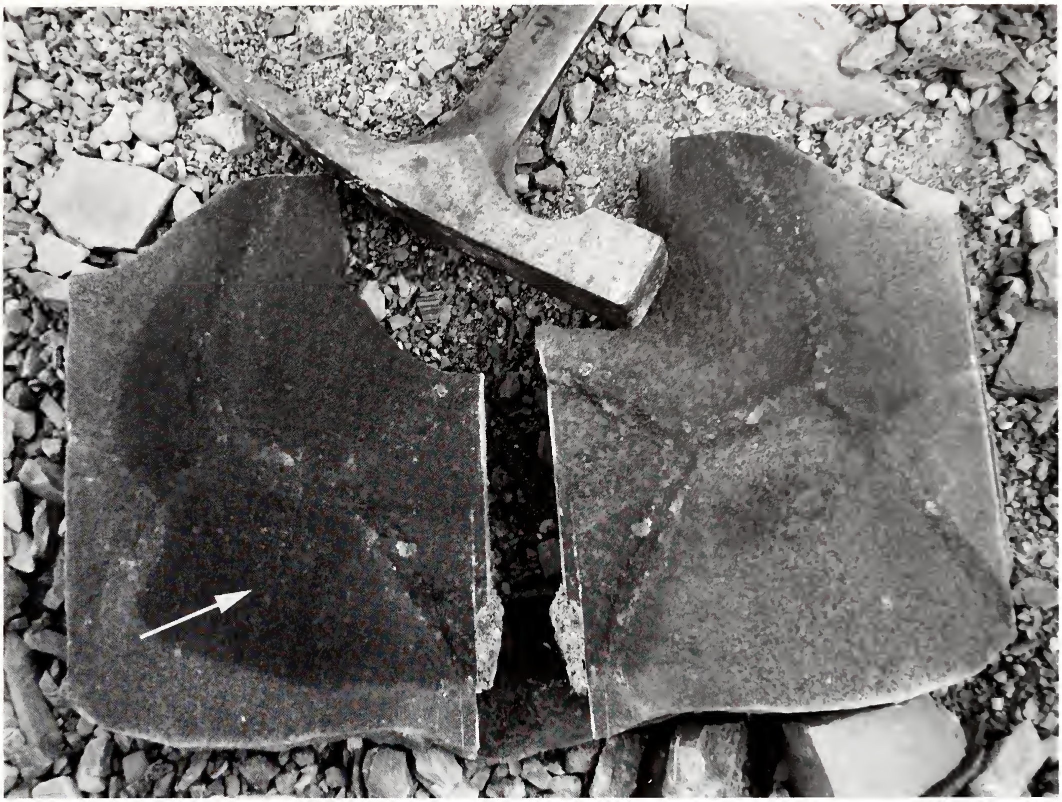

Figure 4.—Split sample from the specimen shown in Fig. 3 reveals a beautiful plane view of the shrinkage polygons with triple junctions. Raindrop imprints are visible at the arrow. The hammer head is about 15 cm long.

Morgan Hill Bed, contained multiple shrinkage crack polygons along an algal mat covered bedding plane. Three sets of polygons were recognized on this surface. The largest polygons were four or five-sided with edges about 5 cm long. The width of the cracks in these polygons was about 5 mm. The second set of polygons had sides of about 2 cm length while the width of their cracks was about 3 mm. The smallest polygons had five or four sides with 5–10 mm length. The width of their cracks was 1–2 mm. No raindrop imprints were noted, but a bumpy irregular algal mat surface was obvious.

Thin section study revealed the presence of shrinkage cracks on a micro scale in both Kokomo Limestone members. We observed and measured several of these cracks that displace 11–16 couplets and extend vertically 2.5–5 mm. In all instances shrinkage began in the darker lamina at or close to the thickest couplet. An increase in the thickness of lamina above the crack was evident (Fig. 5). Sparry calcite cement and scattered quartz silt filled the micro-cracks. The thickness of dark-light couplets varied from 0.2–0.7 mm.

The Eel Bed of the Kokomo Limestone shows more variations in color than the Morgan Hill Bed. The Eel Bed contains numerous layers with vugs and bird's-eye structures and doesn't weather easily along bedding planes. In many layers vugs are filled with either calcite or tar. While the bedding plane surfaces were poorly exposed and hard to study, there are plenty of easily accessible side views with abundant vugs and disrupted and broken laminae. In its lower 3 m, the Eel Bed contains 1–3 cm structureless and vuggy beds intercalated with thinly-laminated (1–5 mm) layers of algal mats, anhydrite and dolomite. In one instance we noticed a ripple mark (Fig. 6) on top of a structureless layer with an irregular upper surface.

The Eel Bed is better exposed and easier to

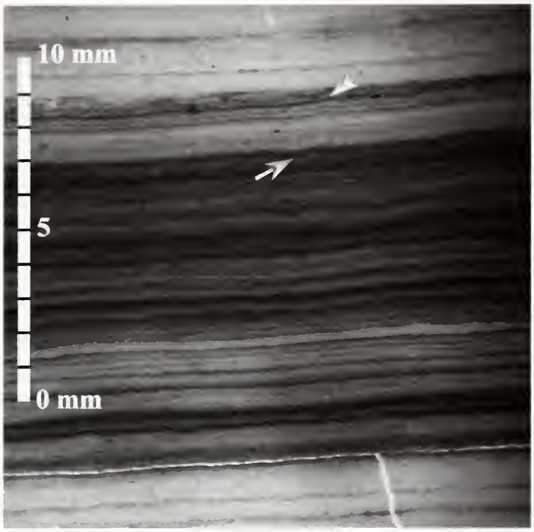

Figure 5.—Shrinkage on micro-scale (between arrows) in Eel Bed of Kokomo Limestone. Note irregular surface of dark lamina where fracture began and its increase in thickness toward left.

study in the now-abandoned Engineering Aggregates Quarry #2. About 2 m below the top of the Eel member there is a prominent 0.5 m thick tan bed that lacks lamination and contains a very porous surface full of vugs and bird's-eye structures. Several layers about 2–3 cm thick (Fig. 7) are full of mudchips that occasionally show imbrication. Mudchips range from 1–10 mm and have well-rounded edges. The bases of these layers are scoured and irregular while their tops are smooth and flat. A thin lamination with dark and light couplets resumes on top of this layer. Vugs are elongated and parallel with bedding planes.

Another common feature from the upper part of the Eel Bed is nodular anhydrite with 5–30 mm long blebs, whose lower sides are always lined with dark algal mats.

DISCUSSION

We agree with Plummer & Gostin's (1981) conclusion that no single feature of a shrinkage crack can distinguish between subaerially formed mudcracks (desiccation cracks) and subaqueously formed synaeresis cracks. However, when several features indicate similar conditions present in various parts of the same depositional environment, then the interpretation makes a valid case. We began our interpretation with samples and structures observed in the lower part of the Morgan Hill Bed (Figs. 2, 3, 4). Multiple generations of cracks break up thinly-laminated carbonate mud in Fig. 2. The V-shape of the cracks and an increase in sediment thickness over the cracks (geopetal fill) indicated subaerial exposure and the growth of algae preferentially around the mudcracks. Broken, rotated and rounded clasts are a clear indication of exposure, desiccation, and reworking during the next high tide.

The different location of the cracks along the vertical profile was an indication of multiple episodes of wetting and drying and time lapse responsible for such a pattern. During exposure, some quartz silt was brought into cracks while evaporite crystals were growing. Later, in diagenesis, dissolution of evaporites provided a source of sulphur that combined with iron to make pyrite. Reducing conditions were provided by the microbial decay of algal mats. Well-defined mud polygons (Fig. 4) with raindrop imprints further support our interpretation of subaerial exposure and the desiccation process. As in the previous example, multiple generations of cracks appear vertically stacked at various positions. Finally, we found an example with multiple generations of cracks developed on an algal mat surface. The largest polygons form first and as the drying proceeds, secondary and then tertiary sets of smaller cracks develop inside the larger polygons. The algal mats preserved some moisture, and the cracks were not very deep or wide.

We are not aware of any syneresis cracks having the properties we recognize and describe in the previous paragraphs, and with great confidence we reject the hypothesis of subaquaeous crack formation in carbonate muds. The somewhat similar structures of diastasis cracks (Cowan & James 1992) may in some cases resemble our examples. However, the Morgan Hill Bed of the Kokomo Limestone is very homogenous and does not contain sediments of different competence that would cause differential mechanical behavior and crack formation.

We agree with Tollefson's (1979) interpretation of an intertidal environment for the Morgan Hill Bed based on the presence of mudcracks. Well-developed mud polygons, multiple stacking and repetition of the patterns vertically, as well as multiple generations of

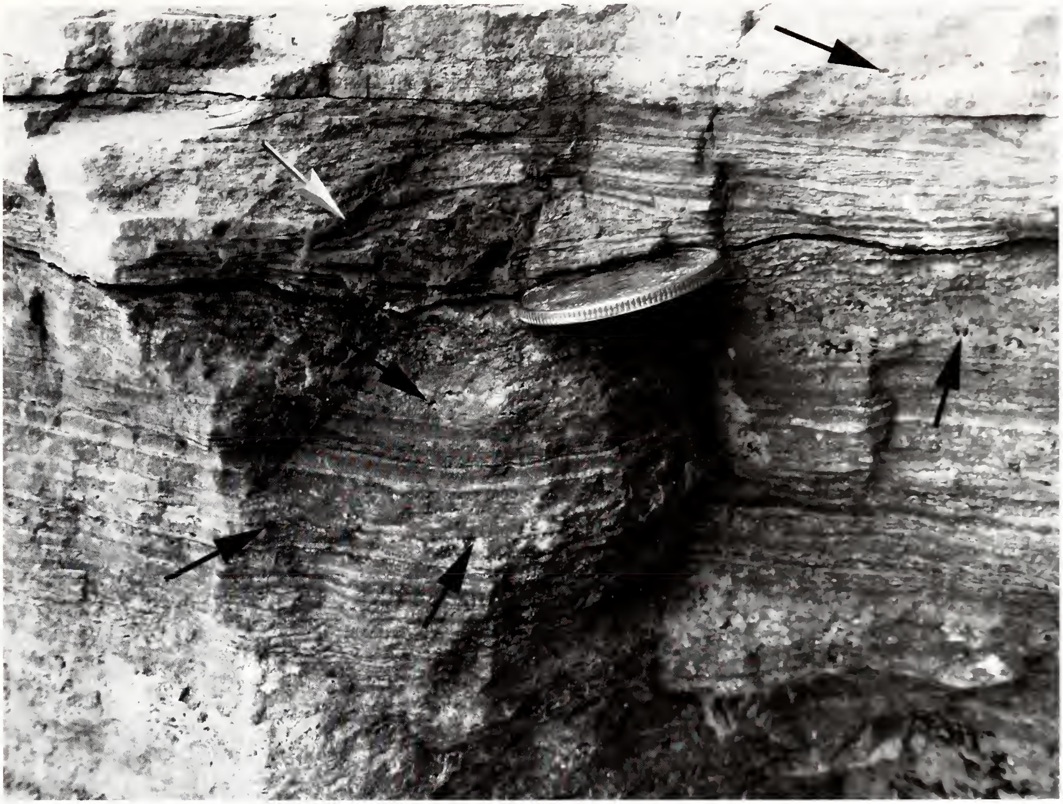

Figure 6.—Lower part of the Eel Bed of Kokomo Limestone. Numerous bird's-eye structures are present (black arrows) in structureless layers. Dark bands in laminated layers are algal mats, while light bands are either dolomite or anhydrite. Grey arrow points to ripple mark on top of irregular structureless, vuggy layer. Coin is 2.5 cm wide.

mudcracks on a single bedding plane, indicate an upper intertidal zone that was under water only during extreme spring tides. On some occasions, dried mud chips were moved and reworked by the following high tide.

Examples of microcracks (Fig. 5) found at various intervals throughout both the Morgan Hill Bed and the Eel Bed show a consistent pattern of crack initiation at or near the thickest couplet. Nellist (1986) did not address these microcracks but rather interpreted our larger mudcracks as synaeresis cracks. He considered laminae couplets to be of seasonal character and suggested synaeresis as a result of seasonal changes in sea water chemistry. Scattered quartz silt that was almost exclusively found within the dark, algal mat laminae is explained by Nellist (1986) as the result of seasonal dryness and availability of silt from distant areas.

Thickening of the laminae from 0.25–0.8 mm occurs in regular intervals of 16–30 couplets. This pattern is indicative of daily and monthly tidal cycles (Brown et al. 1990; Kvale et al. 1999) rather than seasonal subtidal deposition. Spring tides deposited the thickest laminae, then brief exposure occurred 6 or 12 h later when micro-cracking occurred. An increase in thickness of subsequent laminae over the microcracks (Fig. 5) indicates their syndepositional origin and brief exposure, rather than later subsurface cracking due to loss of pore water or dewatering due to earthquake ground motion (Pratt 1988). Preferential accumulation of quartz silt in dark, algal-mat laminae can be explained either by trapping of silt by exposed algal mats, or by the settling of silt through shallow water on top of algal mats during flood tides. We interpreted intervals with microcracks as an indication of the middle intertidal zone which was exposed only during extreme low spring

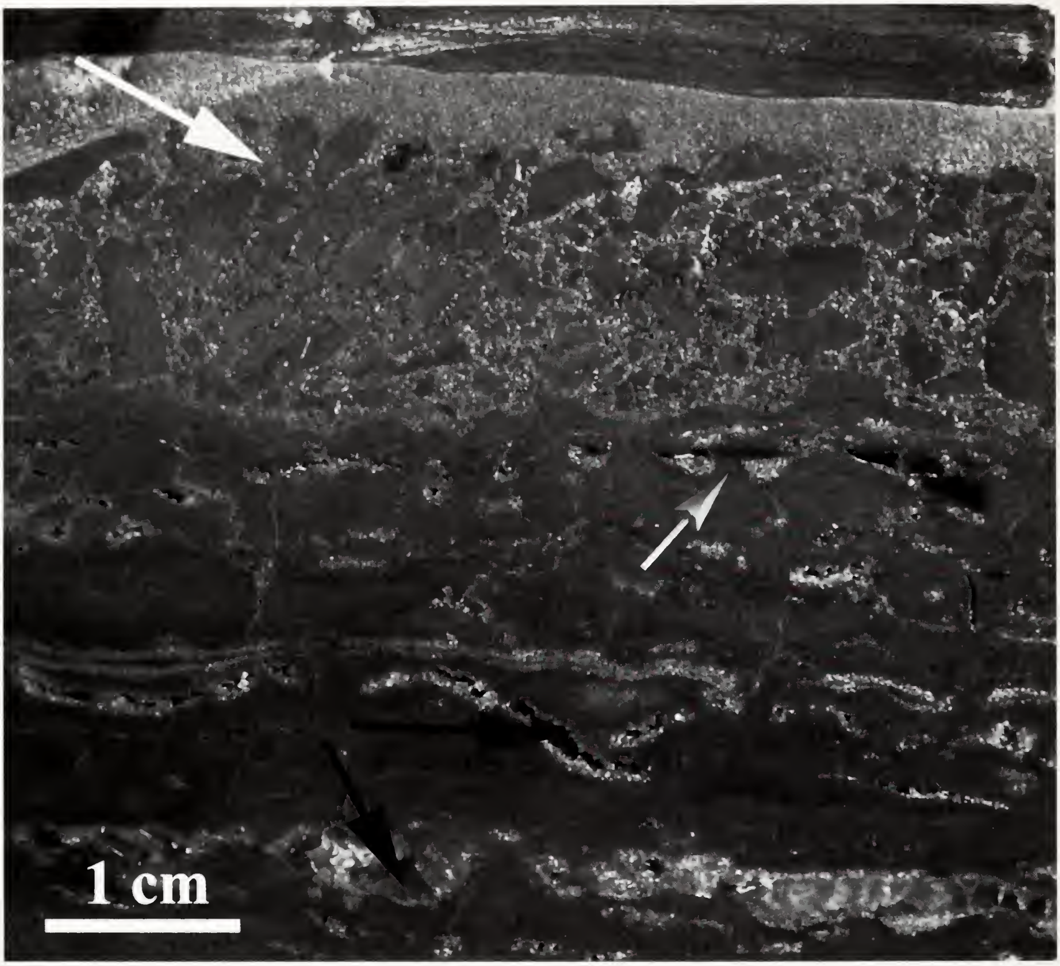

Figure 7.—Intraformational conglomerate layer (white arrow) with irregular scoured base, from the upper part of Eel Bed. Bird's-eye structures are scattered throughout the lower part of the sample. Some vugs have geopetal fill (grey arrow). Elongated vugs (black arrows) are filled with calcite and dolomite or are empty, but in other exposures contain tar or pyrite. Note lamination at the top of the sample.

tides. We correlate the Morgan Hill Bed and lower laminated parts of the Eel Bed of the Kokomo Limestone with the Salina Formation Unit A-1, lithofacies 2 (Gill 1977) representing an intertidal depositional environment that was frequently but briefly exposed to drying and desiccation.

Intraformational conglomerate, bird's-eye (fenestrate) structures, and abundant vugs (Fig. 6) are reliable indicators of supratidal depositional environment (Ginsburg 1975; Demico & Hardie 1994; Flugel 2004). During storms, highly sediment-charged water moves over supratidal flats and within a few hours layers exceeding 2 cm in thickness may be deposited (Shinn 1983). The upper part of our Fig. 7 represents one storm event which reworked dried mudchips into a 2 cm thick layer. Even though rare, ripple marks have been reported from a supratidal carbonate environment after passage of a storm (Shinn 1983).

Bird's-eye structures and vugs form in supratidal sediments as a result of shrinkage and expansion, gas bubble formation, air escape during flooding, wrinkles in algal mats or even by development of evaporites (Shinn 1968). Supratidal bird's-eye structures are preserved because of early cementation and filling with calcite, dolomite, evaporite or internal sediment (Shinn 1968, 1983). Perkins

(1963) described very similar bird's-eye structures in dolomite beds in the Devonian Jeffersonville Limestone, intercalated with laminated and mudcracked beds. Numerous bird's-eye structures and vugs in the Eel Bed of the Kokomo Limestone are filled with calcite, dolomite or geopetal fill and clearly indicate a supratidal depositional environment.

Formation of anhydrite and gypsum occurs mostly in the upper intertidal and supratidal environments, just centimeters above mean tide level. Capillary rise brings salty groundwater to the surface, where evaporation increases concentration of brines and eventually causes precipitation of gypsum or anhydrite (Shinn 1983). Gypsum may form during the dry season on humid tidal flats, such as in the Bahamas, but it is dissolved during the wet season and is not preserved in the rock record. In arid tidal flats, such as Persian Gulf sabkha, gypsum precipitates in a transitional zone between intertidal and supratidal conditions, while anhydrite precipitates in the supratidal zone (Shinn 1983).

Tollefson (1979) considers the Eel Bed to be the result of a normal marine, subtidal depositional environment, while Nellist (1986) argues in favor of an intertidal depositional environment. Most of our evidence, however, clearly suggests that during the deposition of the Eel Bed an arid supratidal sabkha was present at this part of Wabash Platform. We correlate the Eel Bed of the Kokomo Limestone with the Salina Formation Unit A-1, lithofacies 4, 5, and 6 (Gill 1977), representing supratidal sabkha depositional environment.

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THE VASCULAR FLORA AND VEGETATIONAL COMMUNITIES OF HAYES ARBORETUM IN WAYNE COUNTY, INDIANA

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ABSTRACT. An inventory of the naturally occurring or naturalized vascular flora occurring at Hayes Arboretum revealed 525 species representing 316 genera and 97 families. The 12 families containing 57% of the documented species were Asteraceae, Poaceae, Cyperaceae, Rosaceae, Ranunculaceae, Liliaceae, Fabaceae, Brassicaceae, Lamiaceae, Apiaceae, Scrophulariaceae, and Caprifoliaceae. Of the documented flora, 375 were native and 150 were adventives. A detailed physiognomic analysis is presented. Of the 525 species reported, 305 represent Wayne County records. The Floristic Quality Index (FQI) for the native species is 72.0, while for all species the FQI is 60.8. The mean Coefficient of Conservatism (C_{av}) for the native species is 3.7, while for all species the C_{av} is 2.7. The mean Wetland Indicator Status (W) for the native species is 0.7, while for all species, the mean W is 1.3. The FQI, C_{av}, and mean W are discussed; and they suggest that Hayes Arboretum is a site with high natural quality that is being compromised by adventives. The vascular flora of Hayes Arboretum includes one rare species, (*Crataegus succulenta*), one endangered species (*Geranium bicknellii*), two threatened species (*Thalictrum pubescens* and *Veronica anagallis-aquatica*), and one species on the watch list (*Panax quinquefolius*). Based on hydrology, soil types, and topography, the major community types (beech-maple forest, mixed hardwood forest in various stages of succession, steep slope and upland woods, floodplain woodland adjacent to Culmer's Run, wet meadows, cattail marsh, seeps, ponds, and fields) are described.

Keywords: Wayne County, Hayes Arboretum, Floristic Quality Index (FQI), county records—vascular plants, plant communities, beech-maple forest, floodplain woods, upland woods, successional woods, cattail marsh, flora—Indiana

Hayes Arboretum is located in the northeast corner of Richmond, Indiana, nestled between U.S. Route 40 and Interstate 70 in Wayne County. It is owned and maintained by the Stanley W. Hayes Research Foundation, Inc. for the use and benefit of the public on a regulated basis. The 202.4 hectare (~ 500 acres) arboretum is a repository for native wild plants indigenous to Wayne County and the counties of the Whitewater Valley Drainage Basin in Indiana and Ohio. It is both an educational facility and a managed nature preserve. As an educational institution, its goals are to provide the public with the best quality resource information available in the area about natural history—especially plants, their disease, care, proper placement, and growth. As a nature preserve, it serves as a permanent habitat for the native flora and fauna of this region.

Under the ownership of Stanley W. Hayes and continuing after the inception of the arboretum in April 1963, the aspiration was to reforest the land with native trees as it was when the first pioneers pushed through this area. Hayes wanted to recreate and protect the natural heritage that the land had to offer. With this aim, much attention was and is placed on the woody flora of the arboretum, with less attention to the herbaceous flora.

There have been several studies of the flora of the arboretum. In 1969, Lindsey et al. (1969) analyzed the woody vegetation in what they termed the "most nearly natural part of the property," the section that the staff refers to as the old-growth woods. They found *Fagus grandifolia* to have the highest importance value based on basal area and density. However, they also reported that high importance values for mature (i.e., over 10 cm dbh) *Prunus serotina* and *Liriodendron tulipifera* and a low one for *Acer saccharum* set this community apart from typical natural maple-beech forest of the region. The most notable study of the herbaceous flora, entitled "Phenology of Wildflowers at Hayes Regional Arboretum," was published in 1975 by Elaine Gandolph Hendricks (1975). Hendricks published the flowering dates of 250 herbaceous plants occurring in the arboretum. Other studies include a list of 251 woody plants (trees, shrubs, and vines) occurring in the arboretum (Staff 1982). In 1994, Paul C. McClure published a list of the vascular plant species at the arboretum (McClure 1994). McClure's list contained over 285 species of plants. In 2001, the Indiana Department of Natural Resources (IDNR) surveyed the old-growth forest north of the Nature Center for potential impact by gypsy moth. In the IDNR report, they noted that many of the large trees were in poor condition due to old age, storm damage, and disease. IDNR also noted the high number of exotic invasive shrubs, 1196 per ha, in the old-growth forest (Jayson R. Waterman, IDNR District Forester, pers. commun.).

An inventory of resources is the necessary first step in developing a long-term resource management plan. Homoya et al. (1985) used floral species composition and distribution as an important component for delineating various natural regions. An inventory is the simplest means to document species diversity and is a fundamental step in monitoring changes that may occur in species composition. Additionally, measures of diversity are frequently seen as indicators of the well-being of ecological systems (Magurran 1988). Given the history of severe anthropogenic disturbance followed by nearly 100 years of aspiring to return the site to its presettlement condition, Hayes Arboretum provides an opportunity for numerous ecological studies, including the long-term monitoring of species composition, size class structure, ecological succession, and the problem of invasive exotics. In this study, our goals were (1) to inventory the natural vascular flora of Hayes Arboretum; (2) to visually estimate the relative distribution of each species; and (3) to describe the seasonal changes in the vegetation for the different habitats. It should be noted that this study concentrated on the natural vascular flora. Species that were planted for educational purposes, such as *Aesculus flava* Aiton and *Rhus aromatica* Aiton, were noted but not included in this inventory even if they may be native to the greater Richmond area.

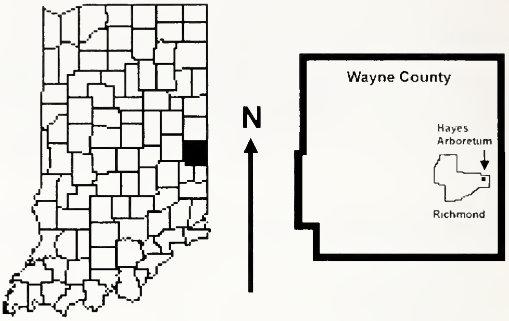

Figure 1.—Location of Hayes Arboretum. Map of Indiana (left) showing the location of Wayne County and Richmond, and the location of Hayes Arboretum in the northeast section of Richmond (right).

THE STUDY AREA

Hayes Arboretum, consisting of approximately 202.4 ha, is located in the northeast corner of Richmond, Indiana in Wayne County (New Paris Quadrangle, north part of the NW one-quarter of Section 35, Township 14 North, Range 1 West; or UTM Zone 16 S, 0684106E by 4412094N [parking lot west of Nature Center], NAD83) (Fig. 1). The property is bordered on the west by Elks Road and some residential sites, on the north by a line of the Pennsylvania Railroad, on the east by Gravel Pit Road, some residential sites and property owned by the Indiana American Water Company Water Company (which is leased to the arboretum), on the southwest by U.S. Route 40, and on the south-central and southeast by Woodside Road. The arboretum is divided into the West Side and the East Side by Hayes Arboretum Road. The East Side, the smaller of the two sections, is currently closed

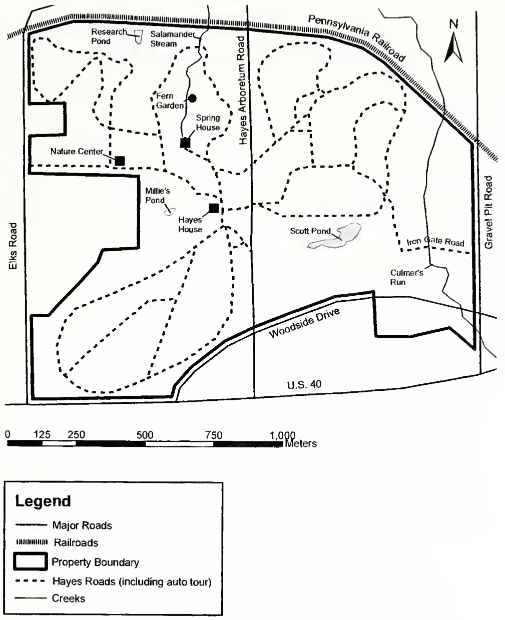

Figure 2.—Map showing the boundary, prominent features, and reference points of Hayes Arboretum. The dash lines indicate the roads within the arboretum, but the auto tour is only in the western section (west of Hayes Arboretum Road).

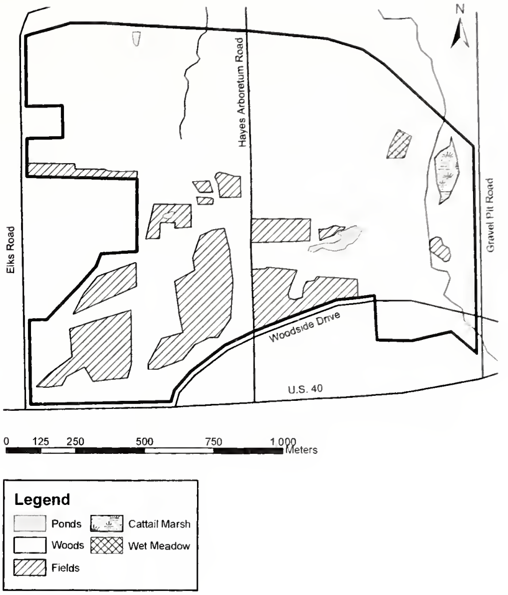

Figure 3.—Map showing the prominent physical features and the major habitat types at Hayes Arboretum.

to the public. An auto tour route runs through the west side (Fig. 2).

Hayes Arboretum contains a variety of natural habitats. The primary types include an older beech-maple woodland, many younger woodlands in various stages of succession, several fields (most manicured but a few with the edges undisturbed), several woodland creeks, one small seasonal pond, one large woodland pond, and one large pond partially shaded by woods, a large cattail marsh, several woodland seeps, three prairie plantings, a railroad embankment, and a variety of roadside habitats (Fig. 3). The wooded areas include hilltop, slope (often steep), and floodplain forests.

Hayes Arboretum lies within the Whitewater River Basin or Watershed. The Whitewater River Basin encompasses 3445 km^2 in southeastern Indiana and 376 km^2 in southwest Ohio and includes all of Wayne and Union counties, most of Fayette and Franklin counties, and parts of Randolph, Henry, Decatur, and Dearborn counties in Indiana and parts of Butler, Darke, Hamilton, and Preble Counties in Ohio. The Whitewater River Basin, which lies within the Miami River Basin of the Ohio River drainage system, extends approximately 120 km along the Indiana-Ohio state line and eventually flows into the Great Miami River, which empties into the Ohio River at the intersection of the Indiana, Ohio, and Kentucky state lines (Indiana Department of Natural Resources 1988; U.S. Environmental Protection Agency 2004; Woodfield 2001).

The Whitewater River has its origin at two sites. The headwaters of the East Fork of the Whitewater River are located in southwestern Darke County, Ohio. The East Fork drains the northeastern part of the Whitewater basin, including Richmond, Indiana (and Hayes Arboretum), as it flows south-southwest. The headwaters of the West Fork of the Whitewater River are located in extreme southern Randolph County, Indiana. The West Fork drains the northwestern and western part of the Whitewater basin, that is, the area west of Richmond. In Franklin County, the West Fork bends southeast to join the East Fork to form the Whitewater River near Brookville, Indiana (Indiana Department of Natural Resources 1988; Thorp 1983; U.S. Environmental Protection Agency 2004; Woodfield 2001).

The Whitewater River Basin includes two physiographic units. The Tipton Till Plain, comprising the northern one-third of the basin, is characterized by flat to gently-rolling terrain, the result of continental glaciation during which glacial till and outwash were deposited as the ice advanced and retreated from Indiana during the Wisconsinan glacial stage (Hedge 1997; Homoya et al. 1985; Melhorn 1997; Woodfield 2001). The headwaters of both the East Fork and West Fork of the Whitewater River occur in the Tipton Till Plain. In contrast, the southern two-thirds of the basin is in the Dearborn-Upland natural area. This part of the basin is a highly dissected bedrock plateau of rugged relief with valley bottoms as much as 150 m (450 feet) lower than the plateau surface (Homoya et al. 1985; Indiana Historical Bureau 2004; Schneider 1966; Thorp 1983; Woodfield 2001).

Hayes Arboretum lies on the border between the Tipton Till Plain and the Dearborn Upland natural areas. The arboretum sets on the top of the plateau just south of the East Fork of the Whitewater River at the easternmost section of the Whitewater Gorge (Thorp 1983). Geologically, the plateau consists of Wisconsinan till (e.g., unconsolidated sediments) that is 15–60 m deep (Indiana Geological Survey 1998). This unconsolidated material sets on the surface of the bedrock, which in the Richmond area is Ordovician shale and limestone (Woodfield 2001) and is part of the Cincinnati Arch (Indiana Department of Natural Resources 1988; Woodfield 2001).

The soil at the arboretum, the Miami-Crosby-Strawn association, is characterized as deep, nearly level to very steep, well-drained to somewhat poorly-drained soil formed dominantly in glacial till, generally occurring on uplands (Blank 1987; Wayne County Resource Inventory Council 2005). Specifically, the major soil type at the arboretum is Miami silt loam, a deep, well-drained soil with slopes (Blank 1987). The majority of the forested sites occur on the Miami silt loam. There is a small section of Eldean loam adjacent to the railroad track. Eldean loam, which supports forests, is a strongly sloping, well-drained soil (Blank 1987). On the west side of the arboretum, the fields and moist to wet woods south of the Hayes House contain Sleeth silt loam and Westland silty clay loam soils. These soils are deep, nearly level, poorly-drained soils (Blank 1987). On the east side of the arboretum, there are pockets of Eldean loam and Sleeth silt loam within the Miami silt loam. These soils are primarily covered by succesional woodlands. In the northern section of the East Side along the railroad, a pocket of Rodman gravelly loam occurs. This type, which is covered with successional woodlands, is characterized as steep to very steep, excessively drained soil on side slopes of outwash plains and moraines (Blank 1987). The final soil type on the East Side is Stonelick loam, a nearly level, deep, well-drained soil on which the floodplain along Culmer's Run occurs.

The Richmond area lies on the Wayne-Henry aquifer system (Indiana Department of Natural Resources 1988; Woodfield 2001). The local system in the Richmond area and Hayes Arboretum flows east. At the arboretum, part of the water from this system flows into Culmer's Run, a creek that flows north and eventually empties into the East Fork of the Whitewater River. On the west side, water flows into Salamander Creek, which flows north and empties into the East Fork of the Whitewater River.

BRIEF HISTORY OF HAYES ARBORETUM

Inhabitants have shaped the land and its use with evidence reaching back to early woodland Indians, including Adena and Hopewell cultures. From some of the earliest records, we have identified the Robert Comer family as having received a land grant for serving in the War of 1812. The Comer family built a log house and began clearing the land for gardens and pasture. In 1833, a large post and beam barn was constructed (which presently serves as the Nature Center). In June 1915, Stanley Hayes began purchasing property including most of the remaining Comer family lands. Hayes was interested for three noted reasons: (1) its location near U.S. 40 and the railroad; (2) the presence of the Indian mounds; and (3) the 25 ha tract of natural woods that reminded him of his youth in central Ohio during the 1870s. Other than this natural woodland, the rest of the land had been cleared. Over the next 20 years, Hayes acquired additional contiguous acres until his purchases concluded in 1935 with a total area of 115 ha.

Several individuals influenced Hayes, two of whom were Luther Burbank and Charles

Deam. Hayes' personal association with these two led him to pursue collections that were native to the area. Extensive tree-replanting programs began in 1923 and continued for 10 years, with approximately 140,000 trees planted. Additional planting projects continued until most all of the cleared land had been replanted except for the areas that were to be kept as meadows and fields. Initial planting stock was selected hardwoods from Tennessee.

In 1959, Hayes created a foundation to receive his land and a good portion of his assets. The Stanley W. Hayes Research Foundation was created for educational and scientific purposes. After Hayes' death in 1963, the Hayes Arboretum project was launched and opened to the general public with the focus being on nature-related education and the display of Hayes' tree collections.

METHODS

During the 2002 and 2003 growing seasons, one to three forays per week were made into the study area. Forays were random but effort was made to cover all areas. Voucher specimens for each species observed were collected and deposited in the Ball State Herbarium (BSUH). Notes on vegetation consisted of species lists with visual estimates of their abundance (see catalog of vascular plants, Appendices 1–4). Additionally, seasonal changes in the dominant vegetation (based on time of flowering) were noted for the various habitats. Nomenclature followed the U.S.D.A. Plants Database (U.S.D.A. 2004). The species documented at Hayes Arboretum are listed in Appendices 1–4.

The floristic quality index (FQI) for the arboretum, calculated only for the plants listed in Appendix 1, was determined using the program developed the Conservation Research Institute in conjunction with Rothrock (2004).

RESULTS

The catalog of the vascular flora of Hayes Arboretum is listed in Appendices 1 to 4. Appendix 1 is a catalog of the naturally-occurring or naturalized vascular flora occurring at Hayes Arboretum. Summarizing this list, the vascular flora at Hayes Arboretum consists of 525 species representing 316 genera and 97 families. Twenty-eight families are represented by only one species. The 12 families with the highest number of species are the Asteraceae (60 species), Poaceae (53 species), Cyperaceae (39 species, including 32 *Carex* spp.), Rosaceae (23 species), Ranunculaceae (20 species), Liliaceae (19 species), Fabaceae (17 species), Brassicaceae (16 species), Lamiaceae (15 species), Apiaceae (14 species), Scrophulariaceae (14 species), and the Caprifoliaceae (12 species). These 12 families account for 302 of the 525 species, or 57.5%, of the species documented at the arboretum. Appendix 2 lists the ferns and their allies documented from the Fern Garden located north of the Spring House. Appendix 3 lists the plant species documented from the three small prairie plantings located south of Hayes House. The plants listed in Appendix 4 are species planted for display and educational purposes. None of the species in Appendix 4 have naturalized, and some are not native to east-central Indiana.

Table 1.—Floristic Quality summary. Mean C is the mean Coefficient of Conservatism, FQI is the Floristic Quality Index, and mean W is the means Wetland Indicator Status.

	Count	Mean C	FQI	Mean W
Native species	375	3.7	72.0	0.7
Total species	525	2.7	60.8	1.3

The physiognomic analysis of the flora, both native and exotic (adventive), for the arboretum reveals that of the 525 plants documented, 375, or 71.4 %, are native and 150, or 28.6%, are adventives. Of the 375 native species, 77 species are woody, 225 are herbaceous vines or forbs, 64 are graminoids, and 9 are ferns and their allies. Of the 150 adventives, 25 are woody, 97 are forbs, and 28 are grasses. The Floristic Quality Indices (FQI), the Coefficients of Conservatism (C), and the Wetland Indicator Status (W) are seen in Table 1. The average W for all species is 1.3 or an average rating of Fac (–).

Based upon the Indiana Natural Heritage Data Center's records for Wayne County, a total of 305 species documented at the arboretum are reported for the first time and represent county records. Lastly, based on the list compiled by the Indiana Natural Heritage program (3 May 1996 draft), the status of several plants at the arboretum is as follows: Rare: *Crataegus succulenta*; Endangered: *Geranium* *bicknellii*; Threatened: *Thalictrum pubescens*, *Veronica anagallis-aquatica*; and on the Watch List: *Panax quinquefolius*.

HABITAT DESCRIPTIONS

The major habitats at Hayes Arboretum include fields (both mowed and non-mowed), roadsides, prairie plantings, woodlands, and wetlands. The woodland types include a beech-maple woods north of the nature center, floodplain woods along Culmer's Run and Salamander Creek, and mixed hardwood forest in various stages of succession. The wetland types include creeks, a woodland seep, three ponds and associated mud flats, a large cattail marsh, and several small wet meadows. Below are descriptions of the vegetation occurring in some of the habitats. See Figs. 2 & 3 for locations of these sites.

Beech-maple forest.—The older woodland lying north of the nature center is the most natural part of the property; and except for the invasive exotics, this woods would be a noteworthy remnant of former beech-maple forest of this region. The most frequent trees of the canopy include *Acer saccharum*, *Carya cordiformis*, *Fagus grandifolia*, *Fraxinus americana*, *Prunus serotina*, and *Quercus rubra*. Trees occurring along the woodland edges or dominating the understory are *Acer platanoides*, *Carpinus caroliniana*, *Cercis canadensis*, *Cornus drummondii*, *Ostrya virginiana*, and *Cercis canadensis*. The most frequent shrubs include *Euonymus alata*, *Ligustrum obtusifolium*, *Lonicera maackii*, *Menispermum canadense*, *Parthenocissus quinquefolia*, *Toxicodendron radicans*, *Viburnum prunifolium*, and *Vitis vulpina*. A large colony of *Aristolochia tomentosa* occurs in the northwest corner along the woods' edge.

The older growth woodland possesses a rich herbaceous layer. There are nearly 20 *Carex* spp., including *C. amphibola*, *C. communis*, and *C. woodii*. Grasses include *Elymus hystrix*, *E. villosus*, *E. virginicus*, *Festuca subverticillata*, and *Poa sylvestris*. Common spring and early summer flowering forbs include *Allium burdickii*, *Arisaema triphyllum*, *Asarum canadense*, *Cardamine concatenata*, *C. douglassii*, *Claytonia virginica*, *Dicentra cucullaria*, *Erigenia bulbosa*, *Galium concinnum*, *Geranium maculatum*, *Geum vernum*, *Hydrophyllum appendiculatum*, *H. macrophyllum*, *Maianthemum racemosum*, *Osmorhiza longistylis*, *Packera obovata*, *Phlox divaricata*, *Podophyllum peltatum*, *Polygonatum biflorum*, *Sanguinaria canadensis*, *Trillium* spp., including *T. grandiflora* (abundant), *Viola pubescens*, and *V. sororia*. Mid-summer to fall flowering forbs include *Ageratina altissima*, *Agrimonia pubescens*, *Campanulastrum americanum*, *Cryptotaenia canadensis*, *Eupatoriadelphus purpureus*, *Helianthus decapetalus*, *Heliopsis helianthoides*, *Polymnia canadensis*, *Sanicula odorata*, *Solidago caesia*, *Symphyotrichum cordifolium*, and *S. lateriflorum*. Although rare in distribution, other noteworthy herbs include *Aralia racemosa*, *Asclepias verticillata*, *Solidago riddellii*, and *Stachys nuttallii*. Although not found during the current study, *Geranium bicknellii* was previously collected at Hayes Arboretum. This is the first report of this species outside of the northeast corner of Indiana. Finally, the two most common ferns of the older woods are *Botrychium virginianum* and *Cystopteris protrusa*.

Mixed hardwood forest.—Primarily occurring on the east side of the arboretum, these woods are variable in age and location, e.g., lowland along small creeks, hillside, and hilltop. These forests contain a wide assortment of tree species, including *Acer saccharum*, *A. negundo*, *Aesculus glabra*, *Carpinus carolinianus*, *Carya cordiformis*, *C. ovata*, *Celtis occidentalis*, *Fagus grandifolia*, *Fraxinus americana*, *F. pennsylvanica*, *Juglans nigra*, *Liriodendron tulipifera*, *Prunus serotina*, *Quercus alba*, *Q. muhlenbergii*, *Q. rubra*, *Tilia americana*, *Ulmus americana*, and *U. rubra*. It is interesting to note that unlike most sites of east-central Indiana, there are no *Crataegus* spp. in the succession woods of Hayes Arboretum. The shrubs, vines, and herbaceous plants are essentially the same as listed for the beech-maple forest above. The noteworthy additions include *Arnoglossum reniforne*, *Carex hitchcockiana*, *Jeffersonia diphylla*, *Polemonium reptans*, *Prenanthes altissima* (abundant on the east side), *Sedum ternatum*, *Veronica anagallis-aquatica*, and *Zizia aurea*.

Steep slope and upland woods.—For whatever innate biological reasons, the steep slope and upland woods between the cattail marsh and Gravel Pit Road supports many species that are not typically found in other parts of the property. Referred to as Chinkapin Slope because of the high number of *Quercus* *muhlenbergii* trees occurring here, this site also supports *Fraxinus quadrangulata*, *Lonicera maackii*, *Rhodotypos scandens*, and *Symphoricarpos orbiculatus*. The latter two occur only at this site. In the southern end of this wooded area is a thick, monoculture of *Lonicera maackii*. Herbaceous plants that are nearly unique to the Chinkapin Slope include *Aureolaria virginica*, *Carex pennsylvanica*, *Delphinium tricorne*, *Dodecatheon meadia*, *Heuchera americana*, *Luzula multiflora*, *Muhlenbergia tenuiflora*, *Ranunculus micranthus*, and *Trillium nivale*.

Floodplain woodland and meadow along Culmer's Run.—The tree species dominating this area include *Acer negundo*, *Aesculus glabra*, *Celtis occidentalis*, *Fraxinus pennsylvanica*, *Juglans nigra*, *Platanus occidentalis*, *Populus deltoides*, and *Ulmus americana*. Some of the shrubs occurring in this area include *Euonymus atropurpurea* (rare), *Lindera benzoin*, *Lonicera maackii*, *Prunus virginiana*, *Rosa multiflora*, *Sambucus nigra* subsp. *canadensis*, and *Viburnum lentago*. The most dominant plant in the herbaceous layer is *Equisetum arvense*. Graminoids of this layer include *Carex* spp., *Cinna arundinacea*, *Glyceria striata*, *Juncus dudleyi*, and *Phalaris arundinacea*. The herbaceous layer is rich in forbs, including *Agrimonia parviflora*, *Eupatorium perfoliatum*, *Floerkea proserpinacoides*, *Galium aparine*, *Hesperis matronalis*, *Impatiens capensis*, *Laportea canadensis*, *Lysimachia ciliata*, *L. nummularia*, *Pilea pumila*, *Rudbeckia laciniata*, *Rumex crispus*, and *Verbesina alternifolia*.

Other wet meadows.—There are two additional noteworthy wet meadows. The first occurs west of Culmer's Run near the railroad track. This meadow was dominated by three plants, *Glyceria striata*, *Leersia oryzoides*, and *Angelica atropurpurea*. This was the only site where purplestem angelica was found. The second is a small sedge meadow just north of the cattail marsh. The creek running through and draining the cattail meadow supplies water that keeps this meadow wet all year. This meadow was dominated by *Carex* spp., especially *C. lurida*, *C. shortiana*, and *C. stipata*. Forbs and grasses occurring at this site include *Chelone glabra*, *Eleocharis erythropoda*, *Lobelia siphilitica*, *Oxypolis rigidior*, *Poa trivialis*, *Polygonum punctatum*, and *Valerianella umbilicata*.

Cattail marsh.—This habitat is dominated by *Typha* spp., especially *T. angustifolia*. Other plants dominating this site include *Bidens cernua*, *Bidens tripartita*, *Carex lurida*, *Carex tribuloides*, *Chelone glabra*, *Eleocharis erythropoda*. *Epilobium coloratum*, *Leersia oryzoides*, *Lycopus americanus*, *L. uniflorus*, *Lysimachia nummularia*, *Mentha piperita*, *Pilea fontana*, *Polygonum hydropiper*, *Rorippa nasturtium-aquaticum*, *Rosa palustris*, *Sagittaria latifolia*, *Solanum dulcamara*, and *Symphyotrichum puniceum*.

Seeps.—There are many minor seeps throughout the property. However, two large seeps occur from the slope running east to west between Gravel Pit Road and Culmer's Run, just south of Iron Gate Road. The larger seep (spring) flows north and supplies the water for the creek running through the cattail marsh. (See "cattail marsh" section for plants associated with this seep.) A smaller seep flows south from this slope forming a large wet area. This site does not support a large number of species throughout the year. The most common species are *Cardamine pensylvanica*, *Carex oligocarpa*, *Cryptotaenia canadensis*, *Impatiens pallida*, *Poa trivialis*, and *Polygonum punctatum*.

Ponds.—Hayes Arboretum includes three ponds that are distinctly different from one another in both their physical environment and biodiversity. Millie's Pond is a small, manmade pond located just west of Hayes House. It is a seasonal pond, receiving full sunlight, and typically holds no water in late summer and fall of most years. Plants found typically only at this site include *Alisma subcordatum*, *Asclepias incarnata*, *Cirsium vulgare*, *Cyperus bipartitus*, *Eragrostis frankii*, *Euthamia graminifolia*, *Salix eriocephala*, *Solidago gigantea*, and *Symphyotrichum novae-angliae*.

Research Pond has the lowest biodiversity due primarily to the fact that it receives very little direct sunlight because it is completely surrounded by woods. It is located in the north-central area of the west side, near the railroad track. Only the free-floating species *Lemna minor* and *Spirodela polyrhiza* occur here. No submergent or emergent vegetation was seen.

Scott Pond is the largest and most botanically-diverse pond. Part of it receives full sunlight, while other parts are partially or fully shaded. The shallow southwestern part holds no water from mid-to-late summer. The northeastern part, next to the dam, is deep with a fairly steep slope. The plants found typically only at Scott Pond include *Cynanchum laeve*, *Cyperus esculentus* var. *leptostachyus*, *Eragrostis frankii* (also at Millie's Pond), *Eupatorium altissimum* (on the dam), *Ludwigia palustris*, *Onoclea sensibilis* (wooded edge of the pond), *Panicum capillare*, *Panicum dichotomiflorum*, *Penthorum sedoides*, *Phyla lanceolata*, *Polygonum lapathifolium*, *Potamogeton foliosus*, *Potamogeton nodosus*, *Scutellaria lateriflora* (drying edge), *Sida spinosa*, and *Xanthium strumarium*.

Fields.—The fields are dominated by grasses, including *Bromus inermis*, *Dactylis glomerata*, *Dichanthelium acuminatum* var. *fasciculatum*, *Digitaria* spp., *Elymus repens*, *Eragrostis* spp., *Lolium arundinaceum*, *Muhlenbergia schreberi*, *Phleum pratense*, *Poa pratensis Setaria* spp., and *Tridens flavus*. One rare grass occurring in the field north of Scott Pond is *Danthonia spicata*. Herbaceous plants dominating the fields include *Achillea millefolium*, *Ambrosia* spp., *Barbarea vulgaris*, *Cichorium intybus*, *Daucus carota*, *Draba verna*, *Erigeron annuus*, *Leucanthemum vulgare*, *Oenothera biennis*, *Pastinaca sativa*, *Penstemon digitalis*, *Solidago* spp., including *Solidago nemoralis*, *Stellaria media*, *Symphyotrichum lanceolatum*, *S. pilosum*, *Trifolium* spp., and *Vernonia gigantea*.

EXOTICS (ADVENTIVES)

As described earlier, Hayes Arboretum contains a high number of exotics. Of the 525 species documented in this study, 150, or 28.6%, are exotics. Most of the exotics were rare and occurred only in one or two sites. For example, *Yucca filamentosa* occurred only on the roadside between the Nature Center and the maintenance building. This species was obviously planted, but it has naturalized and is spreading at this site. Likewise, *Akebia quinata*, which was apparently planted, has become well-established in the small woods south of Hayes House. *Vincetoxicum nigrum* (*Cynanchum louiseae*) occurs in two large colonies. One is located along the red trail just south of Millie's Pond and the second along the railroad track between Elks Road and Hayes Arboretum Road. *Philadelphus coronarius*, which was planted on roadsides along the auto tour south of Hayes House, has naturalized and become somewhat invasive.

Many adventives only occurred along the railroad track forming the northern border of the arboretum. These include *Aegilops cylindrica*, *Bromus racemosus*, *Bromus tectorum*, *Camelina microcarpa*, *Galium mollugo*, *Glycine max*, *Hordeum pusillum*, *Papaver dubium*, *Silene latifolia*, *Triticum aestivum*, and *Zea mays*. Likewise, several exotics were only abundant in the cattail marsh, including *Mentha* x *piperita* and *Rorippa nasturtium-aquaticum*.

There are a number of exotics species that have become widespread within the arboretum. *Acer platanoides* and *Duchesnea indica* are common in the woods just north of the Nature Center. Although infrequent, *Berberis thunbergii* occurs throughout these woods. *Euonymus alata* is common throughout the woods on the west side and is abundant in the woods between the Spring House and the fern garden. Although widespread, *Alliaria petiolata and Rosa multiflora* are not as common at the arboretum as other localities we have examined. *Hesperis matronalis* is a growing problem in the floodplain woods along Culmer's Run on the east side. Two exotic species abundant only on the east side are *Polygonum cespitosum*, which occurs along and in the dirt roads, and *Veronica hederifolia*, which occurs north from Iron Gate Road along the valley and hillside to the seep and around the east side of the cattail marsh.

In addition to *Euonymus alata*, the five most invasive adventives are *Ligustrum obtusifolium*, *Lonicera maackii*, *Maclura pomifera*, *Rhodotypos scandens*, and *Vinca minor*. *Ligustrum obtusifolium* was originally planted, but through the years it has become widespread along woody roadsides and throughout the woods, especially on the west side. *Lonicera maackii* is the most widespread exotic, occurring throughout the woods on both sides. It is so dense on the trail from the seep to the top of the hill on the east side that it has crowded out all other understory vegetation. *Maclura pomifera*, introduced to the midwestern U.S. from the western U.S., occurs along woody edges and open woods. A large colony of *Rhodotypos scandens* is growing in the upland woods between the cattail marsh and Gravel Pit Road. This species probably moved into the arboretum from the residences along Gravel Pit Road. Once it was established, this species spread rapidly. Lastly, there are five or six colonies of *Vinca minor*. Although a relatively slow-growing exotic, it has become established in various woodland sites on the west side. One colony, located east of the Research Pond near the railroad track, covers about 0.1 ha.

DISCUSSION

The native and naturalized vascular flora at Hayes Arboretum includes the same core of plants, and consequently plant families, reported for other comparative sites in east-central Indiana (Rothrock et al. 1993; Rothrock 1997; Ruch et al. 1998, 2002, 2004; Stonehouse et al. 2003). These 12 plant families include the Apiaceae, Asteraceae, Brassicaceae, Caprifoliaceae, Cyperaceae, Fabaceae, Lamiaceae, Liliaceae, Poaceae, Ranunculaceae, Rosaceae, and Scrophulariaceae. In all of these studies as well as in the current one, these 12 families account for more than 50% of the plants reported. The flora at Hayes Arboretum is dominated by herbaceous plant species (413 species or 78.7%) including forbs (322 species), grasses (53 species), and sedges (39 species). Woody species (103 species) comprise 19.6% of the total species including trees (53 species), shrubs (35 species), and woody vines (15 species). Ferns and their allies account for only 1.7% (9 species) of the total.

Based on the inventory of the native vascular flora, Hayes Arboretum has a floristic quality index (FQI) of 72.0, with a mean coefficient of conservatism (C_{av}) of 3.7. The FQI indicates that the arboretum is of nature preserve quality, and suggests that it contains "noteworthy remnants of a region's natural heritage" (Rothrock & Homoya 2005). The FQI at the arboretum exceeds or is similar to those at Barker Woods Nature Preserve in LaPorte County (FQI = 60.7), Bendix Woods Nature Preserve in St. Joseph County (FQI = 49.3), Botany Glen in Grant County (FQI = 68.5), Fall Creek Gorge Nature Preserve in Warren County (FQI = 64.1), Fogwell Forest Nature Preserve in Allen County (FQI = 59.3), Ginn Woods in Delaware County (FQI = 74.1), Hemlock Bluff Nature Preserve in Jackson County (FQI = 64.9), Lick Creek Summit in Wayne County (FQI = 68.9), and Wilbur Wright Fish and Wildlife Area in Henry County (FQI = 77.3) (Rothrock & Homoya 2005). The FQI at Mounds State Park (87.3) is considerably higher than that for the Hayes Arboretum.

According to Swink & Wilhelm (1994), species inventories from sites of natural quality will attain a C_{av} or 3.5 or higher, while those with high natural quality might be expected to have a C_{av} of 4.5 or greater. Because the average Indiana C values are 1.2 cohorts lower than those of the Chicago region (Rothrock & Homoya 2005), it is reasonable to anticipate that sites with high natural quality may have somewhat lower C_{av} values than those suggested by Swink & Wilhelm (1994). Rothrock & Homoya (2005) indicate that the best quality reference sites in central Indiana had C_{av} ranging from 3.8–4.1. The C_{av} of 3.7 for Hayes Arboretum, therefore, suggests that the site has remnant natural quality, although not in the higher quality category. The C_{av} for Hayes Arboretum is similar to those obtained for sites in neighboring counties, e.g., Ginn Woods in Delaware County (C_{av} = 3.9), and Wilbur Wright Fish and Wildlife Area in Henry County (C_{av} = 3.9). The C_{av} for Hayes Arboretum was lower than that for the other studies cited above (C_{av} of 4.0–4.5) with the exception of Fall Creek Gorge Nature Preserve (Rothrock & Homoya 2005). This may be due in part to the sampling procedure. As in our other studies at Ginn Woods and at Wilbur Wright Fish and Wildlife Area (Ruch 1998, 2002, 2004), we documented plants to the asphalt roads, to the railroad tracks, in manicured field and lawns, and in gardens and other disturbed areas. In addition to containing a high number of exotic species, these sites also include an inordinate number of native plants with low C values. Regardless of this, the lower C_{av} for the Hayes Arboretum compared to other sites suggests that for whatever historical or innate biological reasons, Hayes Arboretum has a limited number of species from the highest fidelity categories. In fact the flora from the arboretum contains only 18 species with C = 8, four species with C = 9, and only one species with C = 10.

The FQI and C_{av} for all species, both native and adventives, reveal additional information about the flora at the arboretum. The FQI for all species is 60.8, more than 10 units lower than the FQI for native species alone. Likewise, for all species, including adventives, the

C_{av} is 2.7, compared to a C_{av} of 3.7 for native species alone. Rothrock & Homoya (2005) have suggested that natural quality of an area is compromised when adventive diversity lowers C_{av} by more than 0.7 units. We documented 150 exotic species at the arboretum. The occurrence of these plants ranged from a few plants in a single location to species that are widespread and often locally abundant. It is obvious from our observations that exotics such as *Euonymus alata*, *Ligustrum obtusifolium*, *Lonicera maackii*, *Rhodotypos scandens*, and *Vinca minor* are having a severe impact on the native flora. In some locations on the east side of the arboretum, the *Lonicera maackii* is growing so thickly that it excludes any other plants. During its survey for the potential impact by gypsy moths on the arboretum in 2001, IDNR noted the high number of exotic invasive shrubs, 1196 per ha, in the old growth forest (Jayson R. Waterman, IDNR District Forester, pers. commun.).

There are several possible reasons for the occurrence of the high number of exotics at Hayes Arboretum. First, Hayes aspired to reforest the land with native trees as it was before European settlement. Although a noble goal, the focus was apparently on trees, with little attention being paid either to the herbaceous layer or especially the shrub layer. Second, due to the focus on trees, once shrubs were introduced, there was no effort to remove or control them. Most of the exotics were introduced by animals, especially birds. However, some, such as *Euonymus alata*, *Ligustrum obtusifolium*, and *Vinca minor*, were introduced by arboretum personnel. Once established, these species have spread, naturalized, and become the dominant species in certain sites. Lastly, except for the original wooded area north of the nature center, referred to as the "old-growth forest" by arboretum personnel, most of the land currently covered by woodlands began as open fields. Although the features of an archetype old-field to mature forest succession can be seen, it is clear that the invasive exotics have altered the process by out-competing and replacing native flora. Additionally, Hayes Arboretum lies within the Richmond city limits. It is bordered on the south by highly-developed U.S. Route 40, residential development on the east and west sides, and fields that drop in elevation to the East Fork of the Whitewater River on the north. As such, it is isolated from other forested areas, particularly mature forests, which could serve as seed sources for native plants.

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APPENDIX 1

CATALOG OF THE NATURAL VASCULAR FLORA AT HAYES ARBORETUM

(arranged alphabetically by family)

Listed are voucher specimens for all naturally-occurring species observed at Hayes Arboretum. Nomenclature follows the U.S.D.A. Plants Database (U.S.D.A. 2005). Each species report contains the following information: (1) current scientific name based on the U.S.D.A. Plants Database; (2) current taxonomic synonyms, if appropriate; (3) common name(s), based primarily on Gleason & Cronquist (1991) and Swink & Wilhelm (1994); (4) typical habitat(s) within the study site; (5) a visual estimate of its relative abundance; (6) its coefficient of conservatism (C-value) for Indiana (Rothrock 2004); and (7) the Ball State University Herbarium (BSUH) number(s).

The relative abundance for species is defined as follows: rare = < five sites although a species may be abundant at one site; infrequent = occasional, not widespread throughout its potential habitats, but may be locally abundant at a site; frequent = common throughout its potential habitats and may be locally abundant at one or more sites; and abundant = common and numerous throughout its potential habitats.

The symbols in parentheses immediately preceding the C values refer to the following: * = naturalized (exotic), non-native species; # = Wayne County record; % = species in Hayes Arboretum herbarium but not found during this study. Species were deemed unreported for Wayne County (and hence considered a county record) if they did not appear in the computer database of Keller et al. (1984). (This is the same list of plants for Wayne County as the one at the Indiana Natural Heritage Data Center, IDNR).

The status categories of certain species in brackets (e.g., [Endangered], [Rare], [Threatened], and [Watch List]) are from the list compiled by the Indiana Natural Heritage Program (3 May 1996).

DIVISION EQUISETOPHYTA
(Scouring Rushes)

Equisetaceae (Horsetail Family)

Equisetum arvense L.; Common or Field Horsetail; Floodplain meadow next to cattail marsh (east side); Frequent; C = 1; BSUH 11896.

Equisetum hyemale L. var. *affine* (Engelm.) A.A. Eat.; Common or Tall Scouring Rush; Along railroad track (east side) and in fern garden; Rare; C = 2; BSUH 11953.

DIVISION POLYPODIOPHYTA
(Ferns)

Aspleniaceae (Spleenwort Family)

Cystopteris protrusa (Weatherby) Blasdell; Common Fragile Fern, Lowland Bladder Fern; Successional and old growth woods; Frequent; (#); C = 4; BSUH 12713.

Diplazium pycnocarpon (Spreng.) Broun; SYN: *Athyrium pycnocarpon* (Spreng.) Tidestrom; Glade Fern; Woods (west side); Rare; C = 9; BSUH 11289, 12986.

Polystichum acrostichoides (Michx.) Schott; Christmas Fern; Woods (west side); Infrequent; C = 5; BSUH 11755.

Onocleaceae (Sensitive Fern Family)

Onoclea sensibilis L.; Sensitive Fern; Wooded bank of Scott Pond; Rare; C = 4; BSUH 11270, 2549.

Ophioglossaceae (Adder's Tongue Family)

Botrychium dissectum Spreng. var. *obliquum* (Muhl.) Clute; Lace-frond Grape Fern, Bronze Fern; Woods; Infrequent; (#); C = 3; BSUH 11999.

Botrychium virginianum (L.) Swartz; Rattlesnake Fern; Woods; Frequent; C = 4; BSUH 11843.

Ophioglossum vulgatum L.; Southern Adder's Tongue Fern; Woods; Rare; (# %); C = 4; Hayes Arboretum Herbarium.

DIVISION CONIFEROPHYTA
(Gymnosperms or Conifers)

Cupressaceae (Cypress Family)

Juniperus virginiana L.; Eastern Red Cedar; Edge of woods and in field; Infrequent; (#); C = 2; BSUH 11666, 12731.

DIVISION MAGNOLIOPHYTA
(Angiosperms)

Acanthaceae (Acanthus Family)

Ruellia strepens L.; Smooth Ruellia, Limestone Wild Petunia; Woods north of Nature Center; Rare; C = 4; BSUH 11072, 11192, 11761.

Aceraceae (Maple Family)

Acer negundo L.; Boxelder; Ash-leaved Maple; Floodplain woods on east side; Infrequent; C = 1; BSUH 11879, 11912.

Acer nigrum Michx. f.; SYN: *Acer saccharum* s. *nigrum*; Black Maple; Floodplain woods on east side; Rare; C = 6; BSUH 11841, 11904.

Acer platanoides L.; Norway Maple; Woods just north of Nature Center; Infrequent, but locally frequent; (* #); C = 0; BSUH 11831.

Acer rubrum L.; Red Maple; Old growth woods near fern garden; Rare; (#); C = 5; BSUH 11885.

Acer saccharinum L.; Silver Maple; Floodplain woods and woods around Scott's Pond; Frequent; C = 1; BSUH 12699.

Acer saccharum Marshall; Sugar Maple; Woods; Abundant; C = 4; BSUH 12611.

Agavaceae (Agave Family)

Yucca filamentosa L.; Adam's Needle, Spanish Bayonet; Roadside east of Nature Center; Rare; (* #); C = 0; BSUH 12586.

Alismataceae (Water Plantain Family)

Alisma subcordatum Raf.; SYN: *Alisma plantago-aquatica* L. ssp. *subcordatum* (Raf.) Hultén; American, Southern, or Common Water Plantain; Millie's Pond; Rare; C = 2; BSUH 11159.

Sagittaria latifolia Willd.; Common or Broadleaf Arrowhead; Cattail marsh; Frequent; C = 3; BSUH 12997.

Amaranthaceae (Amaranth Family)

Amaranthus retroflexus L.; Redroot, Rough Pigweed, Redroot Amaranth; Disturbed ground near Nature Center; Rare; (* #); C = 0; BSUH 12622, 12631.

Anacardiaceae (Cashew Family)

Rhus glabra L.; Smooth Sumac; Field near Scott's Pond; Rare; (#); C = 1; BSUH 11115.

Toxicodendron radicans (L.) Kuntze var. *negundo* (Greene) Reveal; Common or Eastern Poison Ivy; Woods and fields; Abundant; (#); C = 1; BSUH 11860.

Annonaceae (Custard Apple Family)

Asimina triloba (L.) Dunal.; Pawpaw; Woods; Infrequent; (#); C = 6; BSUH 11837.

Apiaceae (Carrot Family)

Angelica atropurpurea L.; Great or Purplestem Angelica; Wet meadow west of Culmer's Run; Rare; C = 6; BSUH 11696.

Chaerophyllum procumbens (L.) Crantz; Spreading or Common Streambank Chervil; Woods on west side; Infrequent; (#); C = 2; BSUH 11797, 12692.

Conium maculatum L.; Poison Hemlock; Moist field and bank of Culmer's Run; Infrequent; (*); C = 0; BSUH 11864.

Cryptotaenia canadensis (L.) DC.; Canadian Honewort; Woods; Abundant; C = 3; BSUH 11862.

Daucus carota L.; Wild Carrot, Queen Anne's Lace; Fields and along railroad track; Frequent; (* #); C = 0; BSUH 12594.

Erigenia bulbosa (Michx.) Nutt.; Harbinger-of-Spring; Woods; Frequent; (#); C = 5; BSUH 11828.

Osmorhiza claytonii (Michx.) C.B. Clarke; Bland or Hairy Sweet Cicely; Woods; Frequent; C = 3; BSUH 12724.

Osmorhiza longistylis (Torr.) DC.; Long-styled Sweet Cicely, Aniseroot; Woods; Abundant; (#); C = 3; BSUH 11669.

Oxypolis rigidior (L.) Raf.; Cowbane; Wet meadow north of cattail marsh; Rare; C = 7; BSUH 11771.

Pastinaca sativa L.; Wild Parsnip; Fields and roadside; Frequent; (*); C = 0; BSUH 12696.

Sanicula canadensis L.; Canada Sanicle, Canadian Black Snakeroot; Woods; Frequent; C = 2; BSUH 11881, 11923, 12688.

Sanicula odorata (Raf.) K.M. Pryer & L.R. Phillippe; SYN: *Sanicula gregaria* Bickn.; Cluster Sanicle, Clustered Black Snakeroot; Woods; Abundant; C = 2; BSUH 12723.

Torilis arvensis (Huds.) Link; Field or Spreading Hedge Parsley; Fields and roadside on east side near Iron Gate Road; Infrequent; (* #); C = 0; BSUH 11989.

Zizia aurea (L.) Koch; Common Golden Alexanders, Golden Zizia; Woods between cattail marsh and Culmer's Run; Rare; C = 7; BSUH 12678, 13000.

Apocynaceae (Dogbane Family)

Apocynum cannabinum L.; Dogbane, Indian Hemp; Fields and season wet area east of Nature Center; Infrequent; C = 2; BSUH 12504.

Vinca minor L.; Common Periwinkle; Woods; Frequent (several large, spreading colonies); (* #); C = 0; BSUH 11827.

Araceae (Arum Family)

Arisaema dracontium (L.) Schott; Green Dragon, Dragon Root; Small woods east of fountain; Rare; C = 5; BSUH 12706.

Arisaema triphyllum (L.) Schott; Jack-in-the-Pulpit, Indian Turnip; Woods; Frequent; C = 4; BSUH 11791.

Araliaceae (Ginseng Family)

Aralia racemosa L.; American Spikenard; Woodland bank near railroad track on west side; Rare; C = 8; BSUH 11976.

Panax quinquefolius L.; American Ginseng; Woods on west side; Rare; C = 7; BSUH 11752. [Watch List]

Aristolochiaceae (Birthwort Family)

Aristolochia tomentosa Sims; Pipe Vine, Woolly Dutchman's Pipe; Northwest corner of west side (a large colony); Rare; (#); C = 7; BSUH 12585.

Asarum canadense L.; Canadian Wild Ginger; Woods; Frequent; C = 5; BSUH 11794.

Asclepiadaceae (Milkweed Family)

Asclepias incarnata L.; Swamp Milkweed; Millie's Pond; Rare; C = 4; BSUH 11179.

Asclepias syriaca L.; Common Milkweed; Field east of Scott Pond; Infrequent; (#); C = 1; BSUH 12658.

Asclepias verticillata L.; Whorled or Horsetail Milkweed; Southeast corner of first intersection on auto tour north of Nature Center; Rare; C = 4; BSUH 11965.

Cynanchum laeve (Michx.) Pers.; SYN: *Ampelamus albidus* (Nutt.) Britt.; Sandvine, Bluevine, Honeyvine; Around Scott Pond; Rare, but locally abundant; (#); C = 1; BSUH 11145, 11340, 12657.

Cynanchum louiseae Kartesz & Gandhi; SYN: *Vincetoxicum nigrum* (L.) Moench; Black Swallowwort; Louis Swallowwort; Open area along red trail south of Millie's Pond and northwest corner of west side along railroad track between Elks Road and Hayes Arboretum Road; Rare (two colonies); (* #); C = 0; BSUH 11086.

Asteraceae (Aster Family)

Achillea millefolium L.; Common Yarrow; Common Milfoil; Fields and roadside; Abundant; C = 0; BSUH 12702.

Ageratina altissima (L.) R.M. King & H. Rob.; SYN: *Eupatorium rugosum* Houtt.; White Snakeroot; Woods; Abundant; C = 2; BSUH 11850, 12643.

Ambrosia artemisiifolia L. var. *elatior* Descourt.; Common or Annual Ragweed; Fields and roadside; Frequent; (#); C = 0; BSUH 11846.

Ambrosia trifida L.; Giant Ragweed; Fields; Abundant; (#); C = 0; BSUH 12634.

Antennaria neglecta Greene; Cat's Foot, Field Pussytoes; Field north of Nature Center; Rare; (# %); C = 3; Hayes Arboretum Herbarium.

Antennaria plantaginifolia (L.) Richards.; Common or Plantain Pussytoes, Woman's Tobacco; Fields east of Nature Center; Rare; (#); C = 3; BSUH 11399, 11906.

Arctium minus Bernh.; Common or Lesser Burdock; Seasonal wet area east of Nature Center and in various fields; Infrequent, but locally abundant; (#); C = 0; BSUH 12503.

Arnoglossum reniforme (Hook.) H. Rob.; SYN: *Cacalia muehlenbergii* (Schultz-Bip.) Fernald, *Arnoglossum muehlenbergii* (Schultz-Bip.) H. Rob.; Great Indian Plantain; Woods and roadside (east side); Infrequent; (#); C = 8; BSUH 12603.

Bidens cernua L.; Nodding Bur Marigold, Nodding Beggar Ticks; In and around cattail marsh; Infrequent; (#); C = 2; BSUH 11732.

Bidens tripartita L.; SYN: *Bidens comosa* (Gray) Wieg.; Three-lobe Beggar's Ticks, Strawstem Beggar's Ticks, Swamp Tickseed; In and around cattail marsh; Infrequent; (#); C = 2; BSUH 12510.

Bidens frondosa L.; Common or Devil's Beggar's Ticks; Wet areas, especially Culmer's Run, Salamander Creek, and Scott Pond; Abundant; (#); C = 1; BSUH 11777, 12516, 12527.

Cichorium intybus L.; Chicory; Fields and roadside; Abundant; (*); C = 0; BSUH 12588.

Cirsium arvense (L.) Scop.; SYN: *Cirsium arvense* (L.) Scop. var. *horridum* Wimmer & Grab.; Field or Canada Thistle; Field around concrete steps on east side; Rare; (*); C = 0; BSUH 12673.

Cirsium discolor (Muhl.) Spreng.; Field or Pasture Thistle; Fields; Abundant; (#); C = 3; BSUH 11170.

Cirsium vulgare (Savi) Ten.; Bull Thistle; North bank of Millie's Pond; Rare; (* #); C = 0; BSUH 11168.

Conyza canadensis var. *canadensis* (L.) Cronquist; Canadian Horseweed; Along railroad track, roadside, and in fields; Frequent; (#); C = 0; BSUH 11106.

Coreopsis tripteris L.; Tall Tickseed, Tall Coreopsis; Southeast corner of first intersection on auto tour north of Nature Center; Rare; (#); C = 8; BSUH 12506.

Elephantopus carolinianus Raeusch.; Leafy or Carolina Elephant's Foot; Woods east of fern garden; Rare; (#); C = 5; BSUH 11968.

Erechtites hieracifolia (L.) Raf.; Fireweed; Fields near Scott Pond and east of the fountain; Infrequent; (#); C = 2; BSUH 11741, 12558.

Erigeron annuus (L.) Pers.; Annual Fleabane, Eastern Daisy Fleabane; Roadside and fields; Frequent; (#); C = 0; BSUH 11857.

Erigeron philadelphicus L.; Philadelphia Daisy; Marsh Fleabane; Field around concrete steps on east side; Infrequent; C = 3; BSUH 11611.

Eupatoriadelphus maculatus (L.) R.M. King & H. Rob.; SYN: *Eupatorium maculatum* L.; Spotted Joe Pye Weed; Wet site along railroad track on west side; Rare; C = 5; 11155.

Eupatoriadelphus purpureus (L.) R.M. King & H. Rob.; SYN: *Eupatorium purpureum* L.; Purple-node or Sweet-scented Joe Pye Weed; In open and closed woods; Frequent; C = 5; BSUH 11440, 12666.

Eupatorium altissimum L.; Tall Eupatorium, Tall Boneset, Tall Thoroughwort; On dam of Scott Pond; Rare; (#); C = 1; BSUH 11736.

Eupatorium perfoliatum L.; Common Boneset; Moist field south of Iron Gate Road; Frequent; C = 4; BSUH 12638.

Euthamia graminifolia (L.) Nutt.; Common Flat-topped Goldenrod, Grass-leaved Goldenrod; Around Millie's Pond; Rare; (#); C = 3; BSUH 11767.

Galinsoga quadriradiata Cav.; Common Quickweed, Peruvian Daisy; Gardens and fields around Nature Center; Rare; (* #); C = 0; BSUH 12690.

Helianthus decapetalus L.; Forest, Pale, or Thin-leaf Sunflower; Woods; Abundant, especially on the east side; (#); C = 5; BSUH 11778, 12669.

Heliopsis helianthoides (L.) Sweet; Sunflower Everlasting, False Sunflower, Smooth Oxeye; Woods; Abundant; C = 4; BSUH 11141, 12656.

Krigia biflora (Walter) S.F. Blake; Two-Flowered False Dandelion, Orange Dwarf Dandelion; Woody roadside bank near gravel pit; Rare; (# %); C = 5; Hayes Arboretum Herbarium.

Lactuca canadensis L.; Tall or Canada Wild Lettuce; along railroad track; Near Scott and Millie's Ponds and edge of woods; Frequent; C = 2; BSUH 11955, 12560, 12659.

Lactuca serriola L.; Prickly Lettuce; Roadside at edge of field near fountain; Rare; (* #); C = 0; BSUH 12559.

Leucanthemum vulgare Lam.; SYN: *Chrysanthemum leucanthemum* L.; Ox-eye Daisy; Roadside and in fields; Infrequent; (* #); C = 0; BSUH 12727.

Matricaria discoidea DC.; SYN: *Matricaria matricarioides* (Less.) Porter; Pineapple Weed, Disc Mayweed; Gravel parking lot near Nature Center; Rare; (*); C = 0; BSUH 12725.

Packera glabella (Poir.) C. Jeffrey; SYN: *Senecio glabellus* Poir.; Butterweed, Yellowtop; Woods' edge in field west of annex; Rare; (#); C = 0; BSUH 11921.

Packera obovata (Muhl.) W.A. Weber & A. Löve; SYN: *Senecio obovatus* Muhl.; Round-Leaved Ragwort, Running Groundsel; Woods and fields; Abundant; C = 7; BSUH 11783.

Polymnia canadensis L.; Pale-flowered or White-flower Leafcup; Woods north of Nature Center, especially along the railroad track; Abundant; C = 3; BSUH 12587.

Prenanthes altissima L.; Tall White Lettuce; Woods; Abundant; (#); C = 5; BSUH 11742.

Ratibida pinnata (Vent.) Barnh.; Globular or Gray Headed Coneflower, Pinnate Prairie Coneflower, Yellow Coneflower; Along the path west of the Spring House; Rare; (#); C = 5; BSUH 11209.

Rudbeckia laciniata L.; Cut-Leaf Coneflower, Wild Golden Glow; Along Culmer's Run; Rare but locally abundant; (#); C = 3; BSUH 11724.

Silphium perfoliatum L.; Cup Plant; Low moist area in woods on west side; Rare; C = 4; BSUH 11413.

Solidago caesia L.; Axillary Goldenrod, Bluestem Goldenrod; Woods; Abundant, especially on west side; C = 7; BSUH 12522.

Solidago canadensis L.; SYN: *Solidago canadensis* L. var. *scabra* T. & G.; Common or Canada Goldenrod; Fields and roadside; Abundant; C = 0; BSUH 11756, 12556.

Solidago gigantea Aiton; Giant, Late, or Smooth Goldenrod; Around Millie's Pond; Rare; C = 4; BSUH 11151.

Solidago nemoralis Aiton; Old-Field or Gray Goldenrod; Fields north and east of Scott Pond; Frequent, but locally abundant in the field to the east; C = 3; BSUH 11757, 12507.

Solidago riddellii Frank; Riddell's Goldenrod; Southeast corner of first intersection on auto tour north of Nature Center; Rare; C = 9; BSUH 12518.

Sonchus asper (L.) Hill; Prickly or Spiny Sow Thistle; Woods' edge and roadside (east side); Frequent; (* #); C = 0; BSUH 12567, 12996.

Symphyotrichum cordifolium (L.) Nesom; SYN: *Aster cordifolius* L.; Common Blue Wood Aster, Common Blue Heart-Leaved Aster; Woods; Abundant, especially on the west side; C = 5; BSUH 12505.

Symphyotrichum cordifolium (L.) Nesom: SYN: *Aster sagittifolius* Willd.; Arrow-leaved Aster, Common Blue Wood Aster; Woods; Abundant, especially on the west side; C = 5; BSUH 12519.

Symphyotrichum lanceolatum (Willd.) Nesom; SYN: *Aster lanceolatus* Willd. var. *simplex* (Willd.) A.G. Jones, *Aster simplex* Willd.; White Panicle Aster, Eastern Lined Aster; Fields on west side; Frequent; (#); C = 3; BSUH 11997.

Symphyotrichum lateriflorum (L.) A. & D. Löve; SYN: *Aster lateriflorus* (L.) Britt.; Goblet, Calico, or Side-Flowering Aster; Fields and woods; Abundant; (#); C = 3; BSUH 11774.

Symphyotrichum novae-angliae (L.) Nesom; SYN: *Aster novae-angliae* L.; New England Aster; Around Millie's Pond; Rare; C = 3; BSUH 11745, 11759, 12553.

Symphyotrichum pilosum (Willd.) Nesom; SYN: *Aster pilosus* var. *pilosus* Willd.; Awl Aster, Hairy White Old-Field Aster; Dry fields; Frequent; (#); C = 0; BSUH 11739.

Symphyotrichum puniceum (L.) A. & D. Löve; SYN: *Aster puniceus* L.; Bristly or Purple-Stem Aster; In and around the cattail marsh; Infrequent; (#); C = 7; BSUH 12529.

Taraxacum officinale Weber; Common Dandelion; Fields and open woods; Frequent; (* #); C = 0; BSUH 11790.

Tragopogon dubius Scop.; Fistulose Goat's Beard; Along railroad track, west side; Infrequent; (* #); C = 0; BSUH 12590.

Tragopogon pratensis L.; Common or Showy Goat's Beard; Northeast corner of east side along railroad track; Rare; (* #); C = 0; BSUH 11925.

Verbesina alternifolia (L.) Britt.; Wingstem; Woods, especially the east side; Abundant; C = 3; BSUH 12647.

Vernonia gigantea (Walt.) Trel.; Tall Ironweed; Fields and roadside; Infrequent; C = 2; BSUH 11723, 12555.

Xanthium strumarium L.; Common Cocklebur; Drying areas of Scott Pond; Abundant at this site; (#); C = 0; BSUH 11762,12512.

Balsaminaceae (Touch-Me-Not Family)

Impatiens capensis Meerb.; Orange or Spotted Touch-Me-Not or Jewelweed; Scattered in moist to wet sites; Frequent; (#); C = 2; BSUH 11987, 12629.

Impatiens pallida Nutt.; Pale or Yellow Touch-Me-Not or Jewelweed; Northeast corner of east side along railroad tracks and around seep south of cattail marsh; Rare, but locally abundant; C = 4; BSUH 12538, 12589.

Berberidaceae (Barberry Family)

Berberis thunbergii DC.; Japanese Barberry; Woods on west side; Infrequent; (* #); C = 0; BSUH 11798.

Jeffersonia diphylla (L.) Pers.; Twinleaf; Slope woods along Iron Gate Road west of Culmer's Run. Rare, but locally frequent; C = 7; BSUH 11832.

Podophyllum peltatum L.; Mayapple; Woods; Abundant; (#); C = 3; BSUH 11624, 11627.

Betulaceae (Birch Family)

Betula papyrifera Marshall; White or Paper Birch; Open woods north of Iron Gate Road (probably planted); Rare; (#); C = 7; BSUH 12684.

Carpinus caroliniana Walt. var. *virginiana* (Marshall) Furlow; American Hornbeam, Blue Beech, Musclewood; Woods; Frequent; C = 5; BSUH 11940.

Ostrya virginiana (Mill.) K. Koch; Hop Hornbeam, Ironwood; Woods; Frequent; (#); C = 5; BSUH 12683.

Bignoniaceae (Trumpet Creeper Family)

Campsis radicans (L.) Seem.; Trumpet Creeper; Woods on west side; Infrequent; (#); C = 1; BSUH 11339, 12502.

Catalpa speciosa Warder; Northern Catalpa, Cigar Tree; Field north of Scott Pond (probably planted); Rare; (#); C = 0; BSUH 12685.

Boraginaceae (Borage Family)

Buglossoides arvensis (L.) I.M. Johnst.; SYN: *Lithospermum arvense* L.; Corn Gromwell; Along railroad track, west side; Rare; (*); C = 0; BSUH 11945, 11995.

Hackelia virginiana (L.) I.M. Johnst.; Stickseed, Beggar's Lice; Woods; Frequent; C = 0; BSUH 11367, 11719.

Mertensia virginica (L.) Pers.; Virginia or Eastern Bluebells; Old growth woods north of Nature Center; Rare; C = 6; BSUH 11799.

Brassicaceae (Mustard Family)

Alliaria petiolata (Bieb.) Cavara & Grande.; Garlic Mustard; Woods and edges of fields; Abundant; (* #); C = 0; BSUH 11784.

Arabis laevigata (Muhl.) Poir.; Smooth Rock Cress; Woods; Infrequent; (#); C = 5; BSUH 11820, 11897.

Barbarea vulgaris Aiton f.; Yellow Rocket; Fields and creek banks; Frequent; (* #); C = 0; BSUH 11834.

Camelina microcarpa DC.; Small-fruited False Flax; Along the railroad tracks, east side; Rare but locally abundant; (* #); C = 0; BSUH 11871, 11933.

Capsella bursa-pastoris (L.) Medik.; Shepherd's Purse; Disturbed ground around Nature Center and roadside; Infrequent; (* #); C = 0; BSUH 11809, 11825.

Cardamine bulbosa (Schreb. ex Muhl.) B.S.P.; SYN: *Cardamine rhomboidea* (Pers.) DC.; Bulbous Bittercress, Spring Cress; Woods, first stretch of auto tour; Infrequent; C = 4; BSUH 11907.

Cardamine concatenata (Michx.) Sw.; Cutleaf or Five-parted Toothwort; Woods; Abundant; C = 4; BSUH 11817.

Cardamine douglassii Britton; Purple Spring Cress, Limestone Bittercress, Northern Bitter Cress; Woods; Frequent; C = 5; BSUH 11890.

Cardamine hirsuta L.; Hoary or Hairy Bittercress; Widespread in woods and fields; Abundant, especially in the east side; (* #); C = 0; BSUH 11592, 11829, 11902.

Cardamine pensylvanica Muhl.; Pennsylvania Bittercress; Wet woods around the seep north of Iron Gate Road, east side; Infrequent; C = 2; BSUH 11845, 11924.

Draba verna L.; Whitlow Grass, Spring Draba, Mouse-eared Whitlow Cress; Fields, roadside, and around the Nature Center; Abundant; (* #); C = 0; BSUH 11892.

Hesperis matronalis L.; Dame's Rocket; Floodplain woods, east side; Infrequent, but locally abundant; (* #); C = 0; BSUH 11835.

Lepidium campestre (L.) Aiton f.; Field Pepper Grass or Pepper Weed, Field Cress; Scattered along railroad track and fields; Infrequent; (*); C = 0; BSUH 11926.

Lepidium virginicum L.; Poor Man's Pepper, Common or Wild Pepper Grass, Virginia Pepper Weed; Scattered along roadsides and in fields; Infrequent; C = 0; BSUH 11852.

Rorippa nasturtium-aquaticum (L.) Hayek; SYN: *Nasturtium officinale* R. Br.; Water Cress; In the creek running through the cattail marsh; Rare but locally abundant; (*); C = 0; BSUH 11861.

Thlaspi arvense L.; Field Penny Cress; Along railroad track, west side; Rare; (* #); C = 0; BSUH 11949.

Campanulaceae (Bellflower Family)

Campanula rapunculoides L.; European, Rover or Rampion Bellflower; Along woodland path west of fern garden; Rare; woods; abundant, especially on the west side; (#); C = 0; BSUH 11069.

Campanulastrum americanum (L.) Small; SYN: *Campanula americana* L.; Tall or American Bellflower; Woods; Abundant; C = 4; BSUH 11994.

Lobelia inflata L.; Indian Tobacco; Woods, fields, around Millie's Pond; Frequent; (#); C = 3; BSUH 11758, 12637.

Lobelia siphilitica L.; Great Blue Lobelia; Moist field south of Iron Gate Road and sedge meadow north of the cattail marsh; Infrequent, but locally frequent; C = 3; BSUH 12636.

Triodanis perfoliata (L.) Nieuwl.; Round-Leaved Triodanis, Clasping Venus's Looking Glass; Along railroad track near Hayes Arboretum Road; Rare; (#); C = 2; BSUH 11958.

Caprifoliaceae (Honeysuckle Family)

Lonicera × *bella* Zabel; Showy Fly or Bell's Honeysuckle; Woods; Rare; (* #); C = 0; BSUH 11918.

Lonicera japonica Thunb.; Japanese Honeysuckle; Fence row along Culmer's Run at Iron Gate Road and around Scott Pond; Infrequent; (* #); C = 0; BSUH 11865, 12998.

Lonicera maackii (Rupr.) Herder; Amur Honeysuckle; Woods; Abundant; (* #); C = 0; BSUH 11922.

Lonicera morrowii A. Gray; Morrow's Honeysuckle; Woods; Infrequent; (* #); C = 0; BSUH 11631.

Lonicera reticulata Raf.; SYN: *Lonicera prolifera* (Kirch.) Rehder; Grape Honeysuckle; McClure Preserve; Rare; (# %); C = 8; Hayes Arboretum Herbarium.

Sambucus nigra L. ssp. *canadensis* (L.) R. Bolli; SYN: *Sambucus canadensis* L.; Common Elder or Elderberry; Floodplain woods and other moist woods; Abundant, especially on the east side; C = 2; BSUH 12563.

Symphoricarpos orbiculatus Moench; Coralberry; Wooded slope northeast of cattail marsh; Rare; (#); C = 1; BSUH 12651.

Viburnum dentatum L. var. *lucidum* Aiton; SYN: *V. recognitum* Fernald; Smooth or Southern Arrow-wood; Edge of woods west of Nature Center; Rare (probably escaped); (* #); C = 0; BSUH 11398.

Viburnum lantana L.; Wayfaring Tree; Woods on east side; Infrequent; (* #); C = 0; BSUH 11937.

Viburnum lentago L.; Nannyberry, Sheepberry; Woods; Infrequent; C = 5; BSUH 11677, 12975.

Viburnum opulus L.; Guelder Rose, European High-Bush Cranberry; Beech woods, east side near Hayes Arboretum Road; Rare; (* #); C = 0; BSUH 12662.

Viburnum prunifolium L.; Black Haw; Woods; Infrequent; (#); C = 4; BSUH 11662, 11838.

Caryophyllaceae (Pink Family)

Arenaria serpyllifolia L.; Thyme-leaved Sandwort; Field; Rare; (* # %); C = 0; Hayes Arboretum Herbarium.

Cerastium fontanum Baumg. ssp. *vulgare* (Hartman) Greuter & Burdet; SYN: *Cerastium vulgatum* L.; Common Mouse-Ear or Big Chickweed; Field around concrete steps in Iron Gate Road; Rare, but locally abundant; woods; infrequent; (* #); C = 0; BSUH 11920.

Dianthus armeria L.; Deptford Pink; Field north of Scott Pond; Rare; (* #); C = 0; BSUH 12574.

Saponaria officinalis L.; Bouncing Bet; Roadside; Infrequent; (* #); C = 0; BSUH 11988.

Silene antirrhina L.; Sleepy Catchfly; Sleepy Silene; Along railroad track, west side; rare, but locally Abundant; (#); C = 0; BSUH 11950.

Silene latifolia Poir. ssp. *alba* (Mill.) Greuter & Burdet; White or Bladder Campion; Woods to railroad track, west side; Infrequent, but locally abundant; (* #); C = 0; BSUH 11960, 12583.

Stellaria graminea L.; Common Stitchwort; Grasslike Starwort; Field south of Millie's Pond and field north of Scott Pond; Rare, but locally frequent; (* #); C = 0; BSUH 12557.

Stellaria media (L.) Vill.; Common Chickweed; Widespread in fields and woods; Abundant; (*); C = 0; BSUH 11796, 11808, 11900.

Stellaria pubera Michx.; Giant or Star Chickweed; Woods; Abundant; C = 7; BSUH 11789.

Celastraceae (Staff Tree Family)

Celastrus orbiculatus Thunb.; Oriental Bittersweet; Floodplain woods east side and old growth woods west side; Rare; (* #); C = 0; BSUH 12681, 13770.

Celastrus scandens L.; American or Climbing Bittersweet; Woods north of Scott Pond; Rare; (#); C = 2; BSUH 12541.

Euonymus alata (Thunb.) Sieb.; Winged Burning Bush, Winged Euonymus; Throughout the woods on the west side, but especially abundant in the woods south of the fern garden; Abundant; (* #); C = 0; BSUH 12719.

Euonymus atropurpurea Jacq.; Eastern Wahoo; Floodplain woods on east side, next to path; Rare; C = 5; BSUH 11855.

Euonymus fortunei (Turcz.) Hand.-Maz.; Wintercreeper; Woods on west side where Salamander Creek flowing under the railroad track; Rare, but locally abundant at this site; (* #); C = 0; BSUH 11807.

Euonymus obovata Nutt.; Running Strawberry Bush; Woods; Infrequent; C = 7; BSUH 13892.

Chenopodiaceae (Goosefoot Family)

Chenopodium album L.; Lamb's Quarters; Along Culmer's Run near Iron Gate Road and disturbed soil; Rare; (* #); C = 0; BSUH 11738.

Clusiaceae (Mangosteen Family)

Hypericum perforatum L.; Common St. John's Wort; Fields; Rare; (* # %); C = 0; Hayes Arboretum Herbarium.

Hypericum punctatum Lam.; Spotted St. John's Wort; Fields and open woods around Scott Pond; Rare; C = 3; BSUH 11425, 12665.

Commelinaceae (Spiderwort Family)

Commelina communis L.; Common or Asiatic Dayflower; Fields and woods edge along railroad track, west side, and near Nature Center; Infrequent; (* #); C = 0; BSUH 12582.

Tradescantia subaspera Ker-Gawl.; Zigzag or Wide-leaved Spiderwort; Woods and woods edge along railroad track; Infrequent; C = 4; BSUH 12597, 12988.

Tradescantia virginiana L.; Virginia Spiderwort; Along railroad track, west side, and woods east of Research Pond; Rare; (#); C = 7; BSUH 11947.

Convolvulaceae (Morning Glory Family)

Calystegia sepium (L.) R. Br.; American or Hedge Bindweed; Woods and field; Infrequent; C = 1; BSUH 12579.

Convolvulus arvensis L.; Field Bindweed; Field next to Woodside Drive; Rare; (*); C = 0; BSUH 12562.

Ipomoea pandurata (L.) G. Mey.; Wild Sweet Potato; Along auto tour east of Hayes House; Rare; C = 3; BSUH 11720.

Ipomoea purpurea (L.) Roth; Common Morning Glory; Field; Rare; (* # %); C = 0; Hayes Arboretum Herbarium.

Cornaceae (Dogwood Family)

Cornus alternifolia L.f.; Pagoda Dogwood, Alternate-leaf Dogwood; McClure Nature Preserve; Rare; C = 8; BSUH 12618.

Cornus drummondii C.A. Mey.; Rough-leaved Dogwood; Open woods, woods' edge and along auto tour; Frequent; (#); C = 2; BSUH 11709, 12676.

Cornus florida L.; Flowering Dogwood; Woods; Rare; C = 4; BSUH 11932.

Nyssa sylvatica Marshall; Black Gum or Tupelo; Old growth woods; Rare (planted?); (#); C = 5; BSUH 11065.

Crassulaceae (Stonecrop Family)

Sedum ternatum Michx.; Woodland or Three-Leaved Stonecrop; Floodplain woods on east side; Infrequent; C = 8; BSUH 11840.

Cucurbitaceae (Gourd Family)

Echinocystis lobata (Michx.) Torr. & A. Gray; Balsam Apple, Wild Cucumber; Old growth woods along path parallel to RR track between Salamander Creek and Research Pond; Rare, but frequent here; (#); C = 3; BSUH 11754.

Sicyos angulatus L.; One-seed Bur Cucumber; Along Culmer's Run; Rare; (#); C = 3; BSUH 12625.

Cyperaceae (Sedge Family)

Carex aggregata Mack.; Smooth Clustered Sedge; Wet areas and moist fields; Frequent to abundant; (#); C = 2; BSUH 11217, 11239, 11241.

Carex albicans Willd. ex Spreng.; Blunt-scaled Oak Sedge; Woods; Infrequent; (#); C = 6; BSUH 11243, 13747.

Carex albursina Sheldon; Blunt-scaled Wood Sedge; Woods; Infrequent; (#); C = 7; BSUH 12663, 13741, 13742.

Carex amphibola Steud.; False Gray Sedge; Woods; Infrequent; C = 8; BSUH 13737, 13738.

Carex blanda Dewey; Common Wood Sedge; Woods and moist field; Frequent; C = 1; BSUH 13733, 13734.

Carex cephalophora Muhl. ex Willd.; Short-headed Bracted Sedge; Old growth woods on west side; Infrequent; C = 3; BSUH 11224.

Carex communis Bailey; Common Beech Sedge; Beech-maple woods on east and west side; Infrequent; (#); C = 8; BSUH 13739.

Carex conjuncta Boott; Green-headed Fox Sedge; Moist field south of Iron Gate Road; Rare; C = 6; BSUH 11222.

Carex digitalis Willd.; Narrow-leaved Wood Sedge; Old growth woods on west side; Rare; C = 7; BSUH 11219.

Carex frankii Kunth; Bristly Cattail or Frank's Sedge; Seasonal wet area just east of Nature Center; Rare, but common here; C = 2; BSUH 11229.

Carex granularis Muhl. ex Willd.; Pale or Limestone Meadow Sedge; Floodplain woods east side and seasonal wet area just east of Nature Center; Infrequent; C = 2; BSUH 11231, 12722.

Carex grisea Wahlenb.; Wood Gray Sedge; Woods; Frequent; (#); C = 2; 11445, 11490, 11502.

Carex hirsutella Mack.; Hairy Green Sedge; Woods; Infrequent; C = 3; BSUH 11478, 11488.

Carex hirtifolia Mack.; Hairy Wood Sedge; Woods; Infrequent; C = 5; BSUH 12721, 13745.

Carex hitchcockiana Dewey; Hairy Gray or Hitchcock's Sedge; Woods; Infrequent; (#); C = 8; BSUH 11486.

Carex jamesii Schwein.; Grass Sedge; Floodplain woods east side; Infrequent; C = 4; BSUH 11485, 13744.

Carex laevivaginata (Kuk.) Mack.; Smooth-sheathed Fox Sedge; Open woods and wet meadow next to cattail marsh and woods; Infrequent; C = 7; BSUH 11483, 11509.

Carex laxiculmis Schwein.; Weak-stemmed Wood Sedge; Woods; Infrequent; (#); C = 7; BSUH 11474, 11505, 11512, 13735, 13736.

Carex laxiflora Lam.; Beech Wood Sedge; Woods; Infrequent; C = 7; BSUH 11497, 13740.

Carex lurida Wahlenb.; Bottlebrush Sedge; Cattail marsh and sedge meadow north of cattail marsh; Abundant; C = 4; BSUH 11515, 11966.

Carex molesta Mack. ex Bright; Field Oval Sedge; Fields and open woods around Scott Pond; Infrequent; (#); C = 2; BSUH 11493, 11503.

Carex normalis Mack.; Spreading Oval Sedge; Fields and open woods around Scott Pond; Infrequent; (#); C = 3; BSUH 11451.

Carex oligocarpa Schk.; Few-fruited Gray Sedge; Seep just south of cattail marsh; Rare, but locally abundant; (#); C = 8; BSUH 11468.

Carex pensylvanica Lam.; Pennsylvania Oak Sedge; Woods; Infrequent; (#); C = 5; BSUH 13743.

Carex radiata (Wahlenb.) Small; Straight-styled Bracted Sedge; Woods; Infrequent; (#); C = 4; BSUH 11471, 11929.

Carex rosea Schk.; Rosy or Curly-styled Bracted Sedge; Woods on west side; Infrequent; (#); C = 5; BSUH 11466, 11517.

Carex shortiana Dewey; Short's Sedge; Seasonal wet areas (along Culmer's Run and just east of the Nature Center) and the sedge meadow just north of the cattail marsh; Frequent; C = 3; BSUH 11530, 11535, 12720.

Carex sparganioides Muhl. ex Willd.; Loose-headed Bracted Sedge; Woods; Infrequent; C = 4; BSUH 11463.

Carex stipata Muhl.; Common Fox Sedge; Open woods and meadow between Culmer's Run and the cattail marsh and in the sedge meadow north of the cattail marsh; Abundant; (#); C = 2; BSUH 11227, 11491.

Carex tribuloides Wahlenb.; Broad-leaved Oval Sedge; Open woods and meadow between Culmer's Run and the cattail marsh; Abundant, especially in cattail marsh; C = 5; BSUH 11374, 11435, 11975.

Carex vulpinoidea Michx.; Brown Fox Sedge; Seasonal wet area just east of Nature Center; Infrequent; C = 2; BSUH 13893.

Carex woodii Dewey; Wood's Stiff Sedge; Woods on the west side; Infrequent; (#); C = 8; BSUH 11465, 13746.

Cyperus bipartitus Torr.; SYN: *Cyperus rivularis* Kunth; Slender or Shining Flat Sedge; Drying areas of Millie's Pond; Rare, but locally frequent; C = 3; BSUH 11747, 11764.

Cyperus esculentus L. var. *leptostachyus* Boeckl.; Field Nut Sedge, Yellow Nut Sedge; Chufa Flat Sedge; Around Scott Pond; Infrequent; (#); C = 0; BSUH 11772, 11970.

Cyperus strigosus L.; False Nut Sedge, Long-scaled Nut Sedge, Straw-colored Flat Sedge; Millie's Pond, drainage ditch along Woodside Drive, and moist field south of Iron Gate Road; Infrequent, but locally frequent; (#); C = 0; BSUH 11743, 11744, 11765.

Eleocharis erythropoda Steud.; Red-rooted Spike Rush; Moist meadow between Culmer's Run and the cattail marsh and in the sedge meadow just north of the cattail marsh; Infrequent; (#); C = 2; BSUH 11496.

Scirpus atrovirens Willd.; Dark-Green Bulrush; Open meadows along Culmer's Run and seasonal wet area just east of Nature Center; Infrequent; C = 4; BSUH 11457, 11748, 12578.

Scirpus hattorianus Makino; Early Dark-Green Bulrush; Open meadows along Culmer's Run; Rare; (#); C = 3; BSUH 11514.

Scirpus pendulus Muhl.; Red or Rufous Bulrush; Along auto tour between Nature Center and Spring House; Rare, but locally abundant; (#); C = 2; BSUH 11876.

Dipsacaceae (Teasel Family)

Dipsacus fullonum L. ssp. *sylvestris* (Huds.) Clapham; SYN: *Dipsacus sylvestris* Huds.; Common or Fuller's Teasel; Floodplain woods, ditches, and cattail marsh; Infrequent; (* #); C = 0; BSUH 11990.

Ebenaceae (Ebony Family)

Diospyros virginiana L.; Common Persimmon; Successional woods just south of Hayes House; Rare; (#); C = 2; BSUH 11718.

Elaeagnaceae (Oleaster Family)

Elaeagnus umbellata Thunb.; Autumn Olive; Scattered in woods and fields; Infrequent; (* #); C = 0; BSUH 11948.

Euphorbiaceae (Spurge Family)

Acalypha rhomboidea Raf.; Rhombic Copperleaf, Virginia Three-seed Mercury; Woods, fields, roadside; Abundant; C = 0; BSUH 11740, 11848.

Chamaesyce maculata (L.) Small; SYN: *Euphorbia maculata* L.; Milk Purslane, Spotted Spurge, Spotted Sandmat; Around Nature Center and roadside; Infrequent; C = 0; BSUH 11728.

Chamaesyce nutans (Lag.) Small; SYN: *Euphorbia nutans* Lag.; Small Eyebane; Dry ground around Scott Pond and roadside; Infrequent; (#); C = 0; BSUH 12660.

Euphorbia dentata Michx.; Toothed Spurge; Woods' edge along railroad track; Infrequent; (#); C = 0; BSUH 12537, 12592.

Fabaceae (Pea or Bean Family)

Amphicarpaea bracteata (L.) Fernald; American Hog Peanut; Along Culmer's Run near Iron Gate Road; Rare; (#); C = 5; BSUH 12627.

Cercis canadensis L.; Eastern Redbud; Woods (especially the edge) and fields; Abundant; (#); C = 3; BSUH 11800, 12728.

Coronilla varia L.; Purple Crown Vetch; Iron Gate Road near Culmer's Run; Rare; (* #); C = 0; BSUH 12694.

Desmodium glutinosum (Muhl.) A. Wood; Cluster-leaf or Pointed-leaf Tick Trefoil; Woods; Infrequent; C = 6; BSUH 11977.

Desmodium paniculatum (L.) DC.; Panicled Tick Trefoil; Fields around Scott Pond; Infrequent; (#); C = 2; BSUH 12664.

Gleditsia triacanthos L.; Honey Locust; Woods on east side; Infrequent; (#); C = 1; BSUH 11941.

Glycine max (L.) Merr.; Volunteer Soybean; Along railroad track; Rare; (* #); C = 0; BSUH 11161.

Medicago lupulina L.; Black Medic; Fields, roadside and around the Nature Center; Infrequent; (*); C = 0; BSUH 12605.

Medicago sativa L.; Common Alfalfa; Field west of Scott Pond; Frequent; (* #); C = 0; BSUH 11107.

Melilotus alba Medik.; White Sweet Clover; Woods' edge along railroad track on the west side; Rare; (* #); C = 0; BSUH 13894.

Melilotus officinalis (L.) Lam.; Yellow Sweet Clover; Woods' edge along railroad track on the west side; Abundant; (*); C = 0; BSUH 11946.

Robinia pseudoacacia L.; Black Locust; Woods; Infrequent, but occasionally locally frequent; (#); C = 1; BSUH 12726.

Trifolium campestre Schreb.; Pinnate or Low Hop Clover; Roadside; Rare; (* # %); C = 0; Hayes Arboretum Herbarium.

Trifolium hybridum L.; Alsike Clover; Fields; Frequent; (* #); C = 0; BSUH 11862.

Trifolium pratense L.; Red Clover; Fields and roadside; Abundant; (* #); C = 0; BSUH 11939.

Trifolium repens L.; White Clover ; Fields; Abundant; (* #); C = 0; BSUH 11962.

Vicia cracca L.; Cow Vetch; Field; Rare; (* # %); C = 0; Hayes Arboretum Herbarium.

Fagaceae (Beech Family)

Fagus grandifolia Ehrh.; American Beech; Old growth woods; Abundant; (#); C = 8; BSUH 12540.

Quercus alba L.; White Oak; Woods; Abundant; (#); C = 5; BSUH 12604.

Quercus imbricaria Michx.; Shingle or Jack Oak; Woods and McClure Preserve; Rare; (#); C = 3; BSUH 11753.

Quercus macrocarpa Michx.; Burr Oak; Woods; Frequent; (#); C = 5; BSUH 12679.

Quercus muhlenbergii Engelm.; Yellow, Chinkapin, or Chinquapin Oak; Woods (especially on the east side); Frequent, occasionally locally abundant; (#); C = 4; BSUH 11842, 12680.

Quercus palustris Muenchh.; Pin Oak; Woods; Rare; (#); C = 3; BSUH 11717.

Quercus rubra L.; Northern Red Oak; Woods; Frequent; (#); C = 4; BSUH 11909.

Fumariaceae (Fumitory Family)

Corydalis flavula (Raf.) DC.; Pale or Short-spurred Corydalis; Woods; Rare; (# %); C = 3; Hayes Arboretum Herbarium.

Dicentra canadensis (Goldie) Walp.; Squirrel Corn; Woods near the overlook on the west side; Infrequent, but locally frequent; (#); C = 7; BSUH 11803.

Dicentra cucullaria (L.) Bernh.; Dutchman's Breeches; Woods; Frequent to locally abundant; (#); C = 6; BSUH 11822.

Geraniaceae (Geranium Family)

Geranium bicknellii Britton; Northern Cranesbill; Sandy roadside; Rare; (# %); C = 9; Hayes Arboretum Herbarium. [Endangered].

Geranium carolinianum L.; SYN: *Geranium carolinianum* L. var. *confertiflorum* Fernald; Carolina Geranium or Crane's Bill; Edge of woods along railroad track on west side; Rare, but locally abundant; (#); C = 2; BSUH 11952.

Geranium maculatum L.; Wild Geranium; Woods; Frequent to abundant; C = 4; BSUH 11675.

Geranium molle L.; Dove's Foot Crane's Bill or Geranium; Roadside along auto tour, north of maintenance buildings; Rare; (* #); C = 0; BSUH 11887.

Grossulariaceae (Gooseberry Family)

Ribes americanum Mill.; Eastern or Wild Black Current; Mouth of small seep in woods near northern entrance into east side; Rare; (#); C = 5; BSUH 13768.

Hippocastanaceae (Horse Chestnut Family)

Aesculus glabra Willd.; Ohio Buckeye; Woods, especially floodplain woods on east side; Frequent; C = 5; BSUH 11596.

Hydrangeaceae (Hydrangea Family)

Hydrangea arborescens L.; American or Wild Hydrangea; Side hills of woods and along railroad track of east side; Infrequent; C = 7; BSUH 11052, 11936.

Philadelphus coronarius L.; European or Sweet Mock Orange; Edge of woods along auto tour south of Hayes House; Rare, but locally frequent; (* #); C = 0; BSUH 12607.

Hydrophyllaceae (Waterleaf Family)

Hydrophyllum appendiculatum Michx.; Biennial or Great Waterleaf; Woods; Abundant; C = 6; BSUH 12715.

Hydrophyllum macrophyllum Nutt.; Hairy or Large-leaf Waterleaf; Woods; Frequent to abundant; C = 7; BSUH 11884.

Iridaceae (Iris Family)

Sisyrinchium angustifolium Mill.; Stout Blue-eyed Grass; Edge of woods' along the railroad track and Gravel Pit Road and in moist fields; Infrequent; C = 3; BSUH 11954, 12995.

Juglandaceae (Walnut Family)

Carya cordiformis (Wangenh.) K. Koch; Bitternut Hickory; Woods; Infrequent; C = 5; BSUH 12575.

Carya laciniosa (Michx. f.) G. Don; Shellbark Hickory; McClure Preserve and along auto tour west of fountain; Rare; (#); C = 8; BSUH 12551.

Carya ovata (Mill.) K. Koch; Shagbark Hickory; Woods north of cattail marsh; Infrequent; (#); C = 4; BSUH 12645.

Juglans nigra L.; Black Walnut; Woods; Infrequent; (#); C = 2; BSUH 12709.

Juncaceae (Rush Family)

Juncus dudleyi Wieg.; Dudley's Rush; Moist fields north and south of Iron Gate Road and around Scott Pond; Frequent, and locally abundant; (#); C = 2; BSUH 13895.

Juncus tenuis Willd.; Path or Poverty Rush; Woodland paths and field around concrete steps on Iron Gate Road; Infrequent; (#); C = 0; BSUH 11454, 11869, 12695.

Juncus torreyi Coville; Torrey's Rush; Cattail marsh; Infrequent; (#); C = 3; BSUH 11969.

Luzula multiflora (Retz.) Lej.; Common Wood Rush; Woods; Infrequent, but locally frequent; (#); C = 6; BSUH 11786, 11787, 13748.

Lamiaceae (Mint Family)

Glechoma hederacea L.; Ground Ivy, Gill-over-the-Ground, Creeping Charlie; Lawns, gardens, moist fields, moist woods; Abundant; (*); C = 0; BSUH 11901, 12718.

Lamium amplexicaule L.; Henbit, Henbit Dead Nettle; Various habitats around the Nature Center; Infrequent; (*); C = 0; BSUH 11806.

Lamium purpureum L.; Purple Dead Nettle; Lawns, gardens, fields, roadside; Frequent; (* #); C = 0; BSUH 11810.

Leonurus cardiaca L.; Common Motherwort; Northeast corner of east side, along woods' edge and railroad track; Rare; (*); C = 0; BSUH 12580.

Lycopus americanus Muhl.; Common or American Water Horehound; Various wet sites throughout arboretum; Frequent; (#); C = 3; BSUH 12661.

Lycopus uniflorus Michx.; Northern Water Horehound or Bugleweed; Floodplain woods along Culmer's Run, cattail marsh, and along Salamander Creek on the west side; Frequent; (#); C = 5; BSUH 11731, 11766, 12511, 12525.

Mentha arvensis L. var. *canadensis* (L.) Kuntze; SYN: *Mentha arvensis* L. var. *villosa* (Benth.) S.R. Stewart; Field or Wild Mint; Various wet areas, but especially moist field south of Iron Gate Road; Infrequent; (#); C = 4; BSUH 12635.

Mentha × *piperita* L.; Peppermint; Cattail marsh; Infrequent, but locally abundant; (*); C = 0; BSUH 11733, 12545.

Monarda fistulosa L.; Wild Bergamot; Edge of woods' along auto tour north of Scott Pond; Rare; C = 3; BSUH 12989.

Nepeta cataria L.; Catnip; Edge of woods along auto tour; Rare; (* %); C = 0; Hayes Arboretum Herbarium.

Prunella vulgaris L.; Common Seal Heal, Lawn Prunella; Lawns, moist fields; McClure Preserve; Infrequent; (*); C = 0; BSUH 11055.

Scutellaria incana Biehler; Downy or Hoary Skullcap; Slope and upland, older successional woods on the east side; Infrequent; C = 4; BSUH 11727, 12987.

Scutellaria lateriflora L.; Mad-dog Skullcap; Moist meadows along Culmer's Run and drying areas of Scott Pond; Infrequent; C = 4; BSUH 11730, 11737.

Stachys nuttallii Shuttlw. ex Benth.; SYN: *Stachys cordata* Riddell; Heart-Leaved Hedge Nettle; Roadside in woods at Salamander Creek; Rare, but locally frequent; C = 7; BSUH 11061.

Teucrium canadense L.; SYN: *Teucrium canadense* var. *virginicum* (L.) Eat.; American Germander; Edge of woods on auto tour east of Nature Center and on Gravel Pit Road; Rare, but locally frequent; C = 3; BSUH 11335.

Lardizabalaceae (Lardizabala Family)

Akebia quinata (Houtt.) Decne.; Five-leaved Akebia, Chocolate Vine; Woods just south of Hayes House; Rare; (* #); C = 0; BSUH 12971.

Lauraceae (Laurel Family)

Lindera benzoin (L.) Blume; Northern or Hairy Spice Bush; Along Salamander Creek on west side and floodplain woods on east side; Infrequent; C = 5; BSUH 12526.

Sassafras albidum (Nutt.) Nees; Sassafras; Edge of woods east of Hayes House; Rare; (#); C = 1; BSUH 11984.

Lemnaceae (Duckweed Family)

Lemna minor L.; Lesser, Small, or Common Duckweed; Culmer's Run and Research Pond; Abundant; (#); C = 3; BSUH 12535.

Spirodela polyrhiza (L.) Schleid.; Great or Giant Duckweed; Research Pond; Abundant; (#); C = 5; BSUH 12534.

Liliaceae (Lily Family)

Allium canadense L.; Wild or Meadow Garlic; Moist field south of Iron Gate Road and open woods north of Iron Gate Road; Abundant; (#); C = 1; BSUH 11622, 11870.

Allium burdickii (Hanes) A.G. Jones; SYN: *Allium tricoccum* Ait. var. *burdickii* Hanes; Narrowleaf Wild Leek; Woods; Abundant; (#); C = 6; BSUH 11813, 11839.

Allium vineale L.; Field or Wild Garlic; Seasonal wet area east of Nature Center and open moist woods between Culmer's Run and cattail marsh; Infrequent; (* #); C = 0; BSUH 11856, 11883.

Asparagus officinalis L.; Garden Asparagus; Field north of Scott Pond, three plants; Rare; (* #); C = 0; BSUH 12701.

Camassia scilloides (Raf.) Cory; Wild Hyacinth, Atlantic Camas; Low areas in woods east of Salamander Creek and north of the fern garden; Rare; C = 5; BSUH 12711.

Convallaria majalis L.; Lily of the Valley; Small woods east of Hayes House; Rare, but locally abundant; (* #); C = 0; BSUH 12668.

Erythronium albidum Nutt.; White Trout Lily, White Adder's Tongue, White Fawn Lily; Woods near fern garden; Rare; (#); C = 3; BSUH 12983.

Erythronium americanum Ker-Gawl.; Yellow Trout Lily, Yellow Adder's Tongue, Dog Tooth Violet; Woods north of Nature Center; Rare; C = 5; BSUH 13897.

Hemerocallis fulva (L.) L.; Orange Day Lily; Iron Gate Road near Culmer's Run; Rare; (* #); C = 0; BSUH 12596.

Lilium michiganense Farw.; Michigan Lily; Woods next to auto tour at Salamander Creek; Rare, but locally frequent; C = 5; BSUH 12985.

Maianthemum racemosum (L.) Link; SYN: *Smilacina racemosa* (L.) Desf.; Feathery False Solomon's Seal; Woods; Abundant; C = 4; BSUH 12717.

Ornithogalum umbellatum L.; Common Star-of-Bethlehem; Seasonal wet area east of Nature Center; Rare; (* #); C = 0; 11624.

Polygonatum biflorum (Walt.) Ell.; Small or Smooth Solomon's Seal; Woods; Frequent; (#); C = 4; BSUH 11882.

Trillium flexipes Raf.; Bent or Declined Trillium, Nodding Wakerobin; Woods north of Nature Center; Rare, two small colonies; (#); C = 5; BSUH 11785.

Trillium grandiflorum (Michx.) Salisb.; Large White or Large Flowered Trillium; Woods north of Nature Center; Abundant; C = 8; BSUH 11782.

Trillium nivale Riddell; Snow Trillium, Dwarf White Wakerobin; Steep wooded hillside east of cattail marsh and in the fern garden; Rare; C = 8; BSUH 11814.

Trillium recurvatum Beck; Prairie or Red Trillium; Woods; Frequent; C = 4; BSUH 11819.

Trillium sessile L.; Toadshade, Sessile Trillium; Slope and upland woods; Frequent, especially on the east side; C = 4; BSUH 11792, 11833.

Uvularia grandiflora Sm.; Large-Flower Bellwort; Woods; Infrequent; C = 7; BSUH 11802.

Limnanthaceae (Meadow Foam Family)

Floerkea proserpinacoides Willd.; False Mermaid Weed; Floodplain woods on east side; Abundant; C = 5; BSUH 11899.

Magnoliaceae (Magnolia Family)

Liriodendron tulipifera L.; Tulip Tree, Tulip Poplar, Yellow Poplar; Woods; Abundant; (#); C = 4; BSUH 12714.

Malvaceae (Mallow Family)

Abutilon theophrasti Medik.; Velvetleaf; Disturbed soil west of Nature Center; Rare; (* #); C = 0; BSUH 12623.

Hibiscus trionum L.; Flower-of-an-Hour; Disturbed ground around butterfly house; Rare; (* #); C = 0; BSUH 11421.

Malva neglecta Wallr.; Common Mallow, Cheeses; Lawn east of Nature Center; Rare, but locally abundant; (*); C = 0; BSUH 11059, 11872.

Sida spinosa L.; Prickly Sida, Prickly Mallow; Drying areas of Scott Pond and woods' edge in northeast corner of east side; Frequent, but locally abundant; (*); C = 0; BSUH 12536.

Menispermaceae (Moonseed Family)

Menispermum canadense L.; Common Moonseed; Woods and woods' edge; Frequent; C = 3; BSUH 11880.

Monotropaceae (Indian Pipe Family)

Monotropa uniflora L.; Indian Pipe; Woods north of Nature Center; Rare; (#); C = 7; BSUH 13896.

Moraceae (Mulberry Family)

Maclura pomifera (Raf.) C.K. Schneid.; Osage Orange, Hedge Apple; Woods; Frequent; (* #); C = 0; BSUH 11867.

Morus alba L.; White Mulberry; Field south of Iron Gate Road, scattered along the edge of woods; Infrequent; (* #); C = 0; BSUH 11914.

Oleaceae (Olive Family)

Fraxinus americana L.; White Ash; Woods; Frequent; C = 4; BSUH 12682.

Fraxinus pennsylvanica Marshall var. *pennsylvanica*; Red Ash; Field along road north of Scott Pond; Rare (one tree); C = 3; BSUH 12602.

Fraxinus pennsylvanica Marshall var. *subintegerrima* (Vahl) Fernald; SYN: *Fraxinus pennsylvanica* Marshall var. *lanceolata* (Borkh.) Sarg.; Green Ash; Woods; Frequent; C = 1; BSUH 12700.

Fraxinus quadrangulata Michx.; Blue Ash; Around Scott Pond and slope and upland woods on east side; Infrequent; (#); C = 7; BSUH 12687, 12999.

Ligustrum obtusifolium Sieb. & Zucc.; Regal Privet, Border Privet; Woods, woods' edge and roadside, throughout but especially the west side; Abundant; (* #); C = 0; BSUH 11873.

Onagraceae (Evening Primrose Family)

Circaea lutetiana L. ssp. *canadensis* (L.) Aschers. & Magnus; Broadleaf Enchanter's Nightshade; Woods and open woods southeast of Hayes House; infrequent, but locally frequent; C = 2; BSUH 11701, 12566.

Epilobium coloratum Biehler; Eastern, Cinnamon, or Purple-leaf Willow Herb; In and around the cattail marsh; infrequent; (#); C = 3; BSUH 11735, 12546.

Ludwigia palustris (L.) Ell.; Common Water Purslane, Marsh Purslane, Marsh Seedbox; Scott Pond; Rare; (#); C = 3; BSUH 12508.

Oenothera biennis L.; Common Evening Primrose; Fields, roadside, along railroad track; Frequent; (#); C = 0; BSUH 11080.

Orchidaceae (Orchid Family)

Corallorhiza odontorhiza (Willd.) Nutt.; Autumn Coral Root; Woods; Rare; (# %); C = 3; Hayes Arboretum Herbarium.

Liparis liliifolia (L.) Rich.; Large Twayblade; Mauve Sleekwort; Brown Widelip Orchid; Woods between Nature Center and Spring House; Rare; (#); C = 3; BSUH 12520.

Spiranthes cernua (L.) Rich.; Nodding Ladies' Tresses; Edge of cattail marsh; Rare; (# %); C = 3; Hayes Arboretum Herbarium.

Orobanchaceae (Broomrape Family)

Epifagus virginiana (L.) W. Bart.; Beech Drops; Old growth woods north of Nature Center; Abundant (but not every year); C = 8; BSUH 11996, 12974.

Oxalidaceae (Wood Sorrel Family)

Oxalis stricta L.; SYN: *Oxalis dillenii* Jacq.; Tall or Common Yellow Wood Sorrel; Various habitats; Frequent; C = 0; BSUH 11959, 12675.

Papaveraceae (Poppy Family)

Papaver dubium L.; Long-Pod, Long-Headed, or Smooth-Fruited Poppy; Along railroad tracks on east side, two large colonies; Rare, but locally abundant; (* #); C = 0; BSUH 11930, 11951.

Sanguinaria canadensis L.; Bloodroot; Woods; Abundant; C = 5; BSUH 11812.

Stylophorum diphyllum (Michx.) Nutt.; Celandine Poppy; Woods north of Nature Center; Rare; (#); C = 7; BSUH 11818.

Phytolaccaceae (Pokeweed Family)

Phytolacca americana L.; American Pokeweed; Along railroad track and open areas in woods; Infrequent; C = 0; BSUH 12593.

Plantaginaceae (Plantain Family)

Plantago lanceolata L.; English or Narrow-leaf Plantain; Lawns, fields, roadside; Frequent; (* #); C = 0; BSUH 11875.

Plantago major L.; Common Plantain; Gravel parking lot east of Nature Center; Rare, but locally frequent; (* #); C = 0; BSUH 11119.

Plantago rugelii Decne.; American or Red-Stalked Plantain; Various sites; Frequent; C = 0; BSUH 11961.

Platanaceae (Plane Tree Family)

Platanus occidentalis L.; American Sycamore; Along Culmer's Run, Salamander Creek, and other moist woodlands; Infrequent; (#); C = 3; BSUH 12599.

Poaceae (Grass Family)

Aegilops cylindrica Host; Jointed Goat Grass; Along railroad track on west side; Rare; (* #); C = 0; BSUH 11546.

Agrostis stolonifera L.; Creeping Bent Grass; Fields and woods; Infrequent; (*); C = 0; BSUH 11547.

Alopecurus pratensis L.; Meadow Foxtail; Wet meadow between Iron Gate Road and the seep; Rare; (* #); C = 0; BSUH 11545.

Andropogon virginicus L.; Broom Sedge Bluestem, Virginia Bluestem, Broom Sedge; Field south of Millie's Pond and roadside along auto tour; Infrequent; (#); C = 1; BSUH 11998, 12981.

Bromus inermis Leyss.; Smooth or Hungarian Brome; Fields and roadside; Frequent, but locally abundant; (* #); C = 0; BSUH 11542.

Bromus japonicus Thunb.; Japanese Chess, Japanese Brome; Woods' edge along railroad track; Infrequent; (* #); C = 0; BSUH 11544.

Bromus racemosus L.; Smooth or Bald Chess or Brome; Along railroad track and roadside; Infrequent, but locally abundant; (* #); C = 0; BSUH 11582.

Bromus tectorum L.; Junegrass, Cheat Grass; Woods' edge along railroad track near Gravel Pit Road; Rare, but locally abundant; (* #); C = 0; BSUH 13749.

Cinna arundinacea L.; Common Wood Reed; Floodplain woods and moist meadows; Abundant; C = 4; BSUH 12644.

Dactylis glomerata L.; Orchard Grass; Fields; Abundant; (* #); C = 0; BSUH 11963.

Danthonia spicata (L.) P. Beauv.; Poverty Oat Grass; Dry field north of Scott Pond; Rare; (#); C = 3; BSUH 11584.

Diarrhena americana P. Beauv.; American Beak Grass; Wooded hillside just north of the Spring House; Rare; C = 5; BSUH 11779.

Dichanthelium acuminatum (Sw.) Gould & C.A. Clark var. *fasciculatum* (Torr.) Freckmann; SYN: *Panicum implicatum* Britton, *Panicum lanuginosum* Ell. var. *implicatum* (Scribn.) Fernald; Woolly, Western, or Old-field Panic Grass; Fields and grassy open woods; Abundant; (#); C = 2; BSUH 11652.

Digitaria ischaemum (Schreb.) Schreb. ex Muhl.; Smooth Crab Grass; Roadside; Infrequent; (* #); C = 0; BSUH 11576.

Digitaria sanguinalis (L.) Scop.; Northern or Hairy Crab Grass; Lawns, fields, roadside; Abundant; (*); C = 0; BSUH 11565.

Echinochloa crusgalli (L.) P. Beauv.; Barnyard Grass; Roadside and in drainage ditches; Infrequent; (*); C = 0; BSUH 11967, 11722.

Eleusine indica (L.) Gaertn.; Yard Grass; Indian Goosegrass; Crowfoot Grass; Roadside; gravel parking lots, along railroad track; Frequent; (* #); C = 0; BSUH 11121, 12539.

Elymus hystrix L.; Eastern Bottlebrush Grass; Woods, especially on east side; Abundant; C = 5; BSUH 12697.

Elymus repens (L.) Gould; SYN: *Elytrigia repens* (L.) Nevski.; Fields on east side; Infrequent; Quack Grass; (* #); C = 0; BSUH 12672.

Elymus villosus Muhl. ex Willd.; Downy or Hairy Wild Rye; Woods; Abundant; (#); C = 4; BSUH 11554, 11559, 11579.

Elymus virginicus L.; Virginia Wild Rye; Woods; Frequent; (#); C = 3; BSUH 11858.

Eragrostis cilianensis (All.) Janchen; Stink Grass; Fields; Infrequent; (* #); C = 0; BSUH 11549.

Eragrostis frankii C.A. Mey.; Sandbar Love Grass; Around Scott and Millie's Ponds, in and along moist dirt roads on the east side; Frequent, but locally abundant; C = 2; BSUH 11749, 11750, 11974.

Eragrostis minor Host; SYN: *Eragrostis poaeoides* Roem. & Schult.; Little, Lesser, or Low Love Grass; Fields and roadsides east of Nature Center; Infrequent; (* #); C = 0; BSUH 11570.

Eragrostis spectabilis (Pursh.) Steud.; Field north of maintenance building; Rare, but locally abundant; Purple Love Grass; (#); C = 3; BSUH 11590, 12515.

Festuca subverticillata (Pers.) E. Alexeev; Nodding Fescue; Woods; Frequent; (#); C = 4; BSUH 11828.

Glyceria striata (Lam.) A.S. Hitchc.; Fowl Manna Grass; Along Culmer's Run and in moist to wet meadows; Abundant; (#); C = 4; BSUH 11586, 12564.

Hordeum pusillum Nutt.; Little Barley; Along railroad track, Rare; (* #); C = 0; BSUH 11575, 13,771.

Leersia oryzoides (L.) Sw.; Rice Cut Grass; Wet field west of Culmer's run and cattail marsh; Infrequent, but locally abundant; C = 2; BSUH 11768.

Leersia virginica Willd.; White Grass; Woods; Frequent; C = 4; BSUH 11303, 11568.

Lolium arundinaceum (Schreb.) S.J. Darbyshire; SYN: *Festuca arundinacea* Schreb., *Festuca elatior* L. var. *arundinacea* (Schreb.) C.F.H. Wimmer, *Schedonorus pratensis* (Hudson) P. Beauv.; Tall Fescue; Fields and roadside; Frequent; (* #); C = 0; BSUH 11868.

Lolium perenne L.; English or Perennial Rye Grass; Fields along Iron Gate Road near Culmer's Run; Rare; (* #); C = 0; BSUH 11691.

Muhlenbergia frondosa (Poir.) Fernald; Common Satin Grass, Wirestem Muhly; Sandy creek bank along Culmer's Run; Rare; (#); C = 3; BSUH 11683.

Muhlenbergia schreberi J.F. Gmel.; Nimblewill; Fields and paths; Abundant; C = 0; BSUH 11657, 11973.

Muhlenbergia tenuiflora (Willd.) B.S.P.; Slender Satin Grass, Slender Muhly; Wooded hillside east of cattail marsh; Rare; (#); C = 7; BSUH 11972.

Panicum capillare L.; Old Witch Grass; Moist area at woods' edge along railroad track and around Scott Pond; Infrequent, but locally abundant near pond; C = 0; BSUH 11641, 11661, 12542.

Panicum dichotomiflorum Michx.; Knee Grass, Fall Panic Grass; Flower gardens around the arboretum and around Scott Pond; Infrequent, but locally abundant around pond; (#); C = 0; BSUH 12514.

Panicum flexile (Gatt.) Scribn.; Slender or Wiry Panic Grass; Grassy roadside along auto tour north of Nature Center; Rare; (#); C = 5; BSUH 11964.

Paspalum setaceum Michx. var. *muehlenbergii* (Nash) D. Banks; SYN: *Paspalum ciliatifolium* Michx. var. *muehlenbergii* (Nash) Fernald; Thin Paspalum, Hairy Lens Grass; Roadside along auto tour north of Nature Center; Rare; C = 3; BSUH 11971.

Phalaris arundinacea L.; Reed Canary Grass; Floodplain meadows and open woods; Frequent, but locally abundant; (* #); C = 0; BSUH 11672.

Phleum pratense L.; Timothy Grass; Fields; Frequent; (* #); C = 0; BSUH 12606.

Poa annua L.; Speargrass, Annual Blue Grass; Waste areas, field edges, and roadside; Abundant; (*); C = 0; BSUH 11815.

Poa compressa L.; Canada Blue Grass; Dry woods and along railroad track, Abundant; (*); C = 0; BSUH 12584.

Poa pratensis L.; Kentucky Blue Grass; Fields and roadside; Abundant; (* #); C = 0; BSUH 13750.

Poa sylvestris A. Gray; Forest or Woodland Blue Grass; Woods; Abundant; C = 5; BSUH 11637, 11938.

Poa trivialis L.; Rough Blue Grass; Seep north of cattail marsh and moist meadows and fields; Abundant; (* #); C = 0; BSUH 11645.

Setaria faberi R. Herrm.; Nodding or Giant Foxtail Grass; Fields and roadside; Frequent, but locally abundant; (* #); C = 0; BSUH 11721.

Setaria pumila (Poir.) Roemer & J.A. Schult. ssp. *pallidifusca* (Schumacher) B.K. Simon; SYN: *Setaria glauca* (L.) Beauv.; Pigeon Grass, Yellow Foxtail Grass; Fields and disturbed ground; Frequent, but locally abundant; (*); C = 0; BSUH 11726.

Sorghum halepense (L.) Pers.; Johnson Grass; Roadside along Woodside Drive; Rare; (* #); C = 0; BSUH 12624.

Sphenopholis intermedia (Rydb.) Rydb.; SYN: *Sphenopholis obtusata* (Michx.) Scribn. var. *major* (Torr.) K.S. Erdman; Slender Wedge Grass; Sunlit trails around Spring House; Rare, but locally abundant; C = 3; BSUH 11877.

Tridens flavus (L.) Hitchc.; Common Purpletop, Purpletop Tridens; Fields; Abundant; (#); C = 1; BSUH 12642.

Triticum aestivum L.; Common Wheat; Edge of woods along railroad track; Rare; (* #); C = 0; BSUH 11957.

Zea mays L.; Volunteer Corn; Edge of woods along railroad track; Rare; (* #); C = 0; BSUH 11101.

Polemoniaceae (Phlox Family)

Phlox divaricata L.; Forest or Wild Blue Phlox; Woods; Abundant; C = 5; BSUH 11788.

Phlox paniculata L.; Summer or Garden Phlox; Woods; Infrequent; C = 3; BSUH 11333, 12614, 12990.

Polemonium reptans L.; Spreading Jacob's Ladder, Greek Valerian; Upland woods west of Iron Gate Road; Rare; C = 5; BSUH 11927.

Polygonaceae (Smartweed Family)

Polygonum aviculare L.; Doorweed, Common or Prostrate Knotweed; Lawns and fields; Frequent; (* #); C = 0; BSUH 11138.

Polygonum cespitosum Blume var. *longisetum* (de Bruyn) Stewart; SYN: *Persicaria caespitosa*; Creeping Smartweed, Oriental Lady's Thumb; Dirt roads and floodplain woods; Frequent, but locally abundant; (* #); C = 0; BSUH 11063, 11991, 12548, 126476.

Polygonum hydropiper L.; SYN: *Persicaria hydropiper* (L.) Opiz; Water Pepper, Marsh Pepper Knotweed; Cattail marsh; Infrequent, but in large colonies; (* #); C = 0; BSUH 11729, 12547.

Polygonum lapathifolium L.; SYN: *Persicaria lapathifolia* (L.) S.F. Gray; Dock-Leaved Smartweed, Curlytop Knotweed, Curlytop Lady's Thumb; Drying banks of Scott Pond; Rare; (#); C = 0; BSUH 11776.

Polygonum pensylvanicum L.; SYN: *Persicaria pensylvanica* (L.) G. Maza; Pennsylvania Smartweed, Pinkweed; Fields around Scott Pond; Infrequent; C = 0; BSUH 11775.

Polygonum persicaria L.; SYN: *Persicaria vulgaris* Webb & Moq.; Spotted Lady's Thumb; Along Culmer's Run and disturbed ground at butterfly house; Infrequent; (*); C = 0; BSUH 11330.

Polygonum punctatum Ell. var. *confertiflorum* (Meisn.) Fassett; SYN: *Persicaria punctata* (Ell.) Small; Dotted Smartweed; Seep north of Iron Gate Road, floodplain woods on east side, and wet meadow north of cattail marsh; Frequent; (#); C = 3; BSUH 11773, 12641.

Polygonum scandens L.; SYN: *Fallopia scandens* (L.) Holub; Climbing False Buckwheat; Climbing on other vegetation throughout the east side; Frequent; (#); C = 0; BSUH 11763, 12533.

Polygonum virginianum L.; SYN: *Tovara virginiana* (L.) Raf.; Jumpseed, Virginia Knotweed; Woods; Frequent; C = 3; BSUH 12649.

Rumex crispus L.; Curly Dock; Moist meadows and open woods east of Culmer's Run; Frequent; (* #); C = 0; BSUH 11705.

Rumex obtusifolius L.; Bitter Dock; Iron Gate Road at Culmer's Run; Rare; (*); C = 0; BSUH 12705.

Portulacaceae (Purslane Family)

Anagallis arvensis L.; Scarlet Pimpernel, Poor Man's Weatherglass; Gravel parking lot south of Hayes House; Rare; (* #); C = 0; BSUH 11853.

Claytonia virginica L.; Virginia Spring Beauty; Woods and dry fields; Abundant; C = 2; BSUH 11823.

Portulaca oleracea L.; Common Purslane; Disturbed ground; Rare; (* # %); C = 0; Hayes Arboretum Herbarium.

Potamogetonaceae (Pondweed Family)

Potamogeton foliosus Raf.; Leafy Pondweed; Scott Pond; Frequent; (#); C = 4; BSUH 11174, 11176.

Potamogeton nodosus Poir.; American or Longleaf Pondweed; Scott Pond; Frequent; (#); C = 4; BSUH 11182.

Primulaceae (Primrose Family)

Dodecatheon meadia L.; Eastern Shooting Star; Fern garden and upland woods east of cattail marsh; Rare; C = 7; BSUH 12710.

Lysimachia ciliata L.; Fringed Loosestrife; Floodplain woods along Culmer's Run and around Scott Pond; Frequent to abundant; C = 4; BSUH 12569, 12577.

Lysimachia nummularia L.; Moneywort; Creeping Jenny; Open wet meadow between Culmer's Run and cattail marsh, cattail marsh, and wet meadow north of cattail marsh; Abundant; (*); C = 0; BSUH 11854.

Ranunculaceae (Buttercup Family)

Actaea pachypoda Ell.; SYN: *Actaea alba* (L.) Miller; Doll's eyes, White Baneberry; Woods; Infrequent; (#); C = 7; BSUH 12712.

Anemone quinquefolia L.; Wood Anemone; Upland woods west of Culmer's Run; Frequent; C = 7; BSUH 11898.

Anemone virginiana L.; Tall Anemone, Tall Thimbleweed; Fields and open woods around Scott Pond; Infrequent; C = 4; BSUH 12571.

Aquilegia canadensis L.; Canada or Red Columbine; Path next to season wet area east of Nature Center; Rare; (#); C = 5; BSUH 12610.

Aquilegia vulgaris L.; European Columbine; Plant dump on east side; Rare; (* #); C = 0; BSUH 11888.

Caltha palustris L.; Yellow Marsh Marigold, Cowslip; Salamander Creek; Rare (one plant); C = 7; BSUH 12972.

Cimicifuga racemosa (L.) Nutt.; Black Cohosh, Black or False Bugbane; Fern garden; Rare; C = 9; BSUH 11978.

Delphinium tricorne Michx.; Dwarf Larkspur; Upland woods east of cattail marsh; Rare; C = 5; BSUH 11602.

Enemion biternatum Raf.; SYN: *Isopyrum biternatum* Torr. & Gray; Eastern False Rue Anemone; Woods; Infrequent; C = 5; BSUH 11795.

Eranthis hyemalis (L.) Salisb.; Mountain Winter Aconite, Hellebore; Edge of woods just east of Nature Center; Rare, but locally abundant; (* #); C = 0; BSUH 13898.

Hepatica nobilis Schreb. var. *acuta* (Pursh) Steyermark; SYN: *Hepatica acutiloba* DC., *Anemone acutiloba* (DC.) G. Lawson; Sharp-lobed Hepatica; Bank of Salamander Creek and the woods west; Infrequent; C = 8; BSUH 11894.

Hydrastis canadensis L.; Golden Seal; Along Salamander Creek in woods between auto tour and railroad track; Rare; (#); C = 7; BSUH 13128.

Ranunculus abortivus L.; Small-Flowering Crowfoot; Little-Leaf Buttercup; Moist fields, woods around Nature Center, and along Culmer's Run; Frequent; C = 0; BSUH 11821.

Ranunculus hispidus Michx. var. *caricetorum*

(Greene) T. Duncan; Bristly Buttercup, Hispid Swamp Buttercup; Floodplain woods along and west of Culmer's Run; Infrequent; C = 10; BSUH 11911.

Ranunculus micranthus Nutt.; Small-Flowered Crowfoot, Rock Buttercup; Slope and upland woods south and east of cattail marsh; Infrequent; (#); C = 4; BSUH 11607.

Ranunculus recurvatus Poir.; Hooked Crowfoot; Wet meadows and along creeks; Infrequent; C = 5; BSUH 11613, 12973.

Ranunculus sceleratus L.; Cursed Crowfoot, Cursed Buttercup; Salamander Creek; Rare; (#); C = 3; BSUH 11639.

Thalictrum dioicum L.; Early Meadow Rue; Upland woods east of the cattail marsh; Rare; C = 7; BSUH 11844.

Thalictrum pubescens Pursh; Late or Tall Meadow Rue; Meadow along Culmer's Run; (This collection may possibly be *Thalictrum perelegans* Greene of Deam [1940], but this species is not recognized by Gleason & Cronquist [1991].); Rare; (#); C = 6; BSUH 11992. [Threatened].

Thalictrum thalictroides (L.) Eames & Boivin; SYN: *Anemonella thalictroides* (L.) Spach.; Rue Anemone; Woods; Infrequent; C = 7; BSUH 11629, 11793.

Rosaceae (Rose Family)

Agrimonia gryposepala Wallr.; Tall Agrimony; Beneath power lines in recently cleared area east of Hayes Arboretum Road and in woods; Infrequent; (#); C = 2; BSUH 11443.

Agrimonia parviflora Aiton; Southern or Swamp Agrimony; Moist fields and meadows and moist open woods; Abundant, especially on the east side; (#); C = 4; BSUH 12653.

Agrimonia pubescens Wallr.; Downy Agrimony; Woods; Frequent; (#); C = 5; BSUH 11327, 12652.

Amelanchier arborea (Michx. f.) Fernald; Downy Serviceberry, Juneberry; Woods north of Nature Center; Rare; (#); C = 6; BSUH 11830, 12521.

Crataegus succulenta Schrad.; Fleshy Hawthorn; Meadow south of Iron Gate Road and west of Culmer's Run; Rare (one tree); (#); C = 6; BSUH 11781. [Rare].

Duchesnea indica (Andr.) Focke; Indian Strawberry; Woods just north of Nature Center; Abundant; (* #); C = 0; BSUH 11805.

Fragaria virginiana Duchesne; Thick-leaved Wild Strawberry; Grassy roadsides and fields; Infrequent, but locally frequent; (#); C = 2; BSUH 11598, 12979.

Geum canadense Jacq.; White Avens; Woods; Infrequent; C = 1; BSUH 11859.

Geum vernum (Raf.) Torr. & Gray; Spring Avens; Woods and moist fields; Abundant; C = 1; BSUH 11594, 11895.

Potentilla norvegica L.; Rough Cinquefoil; fields; infrequent; C = 0; BSUH 12595.

Potentilla recta L.; Sulphur Five-fingers or Cinquefoil; Fields and roadside; Infrequent; (*); C = 0; BSUH 12601.

Potentilla simplex Michx.; Old Field Five-Fingers, Common Cinquefoil; Woods and woods edge, especially along the railroad track on the west side; Frequent, but locally abundant; C = 2; BSUH 11934.

Prunus americana Marshall; American or Wild Plum; Edge of woods along auto tour; Infrequent; C = 4; BSUH 12984, 13769.

Prunus serotina Ehrh.; Wild Black Cherry; Woods; Frequent; C = 1; BSUH 12612.

Prunus virginiana L.; Common Choke Cherry; Floodplain woods on east side; Infrequent, but locally abundant; (#); C = 3; BSUH 11641.

Pyrus malus L.; Apple; SYN: *Malus domestica* Borkh.; Fields and woods; Infrequent; (* #); C = 0; BSUH 11826, 12982.

Rhodotypos scandens (Thunb.) Makino; Jetbead; Upland woods east of cattail marsh; Abundant at this site; (* #); C = 0; BSUH 11889.

Rosa multiflora Thunb.; Multiflora or Japanese Rose; Woods; Frequent; (* #); C = 0; BSUH 11874.

Rosa palustris Marshall; Swamp Rose; Cattail marsh and banks of Scott Pond; Infrequent; C = 5; BSUH 11116, 12530.

Rosa setigera Michx.; Climbing Prairie Rose, Illinois Rose; Woods' edge; Abundant; C = 4; BSUH 11189, 12598.

Rubus flagellaris Willd.; Common or Northern Dewberry; Sunlit areas of woods; Infrequent; (#); C = 2; BSUH 11396, 11626.

Rubus occidentalis L.; Black Raspberry; Woods edge; Infrequent; C = 1; BSUH 11956.

Rubus pensilvanicus Poir.; SYN: *Rubus abactus* Bailey; Pennsylvania or Yankee Blackberry; Along the railroad track and scattered sites in open woods or the edge of woods; Infrequent; (#); C = 5; BSUH 11935, 11943.

Rubiaceae (Madder Family)

Galium aparine L.; Cleavers, Annual Bedstraw; Successional woods, especially on the east side; Abundant; C = 1; BSUH 11910.

Galium circaezans Michx.; Forest Bedstraw, Smooth Wild Licorice, Licorice Bedstraw; Woods, especially on the east side; Abundant; C = 7; BSUH 11944, 12677.

Galium concinnum Torr. & Gray; Shining Bedstraw; Woods; Frequent; C = 5; BSUH 12573.

Galium mollugo L.; White Bedstraw; Woods' edge along railroad track on the west side; Rare, but locally abundant; (* #); C = 0; BSUH 12581.

Galium triflorum Michx.; Sweet-scented or Fragrant Bedstraw; Woods on the east side; Infrequent; (#); C = 5; BSUH 11406.

Rutaceae (Rue Family)

Ptelea trifoliata L.; Common Hop Tree, Smooth Wafer Ash; Woods' edge near Spring House and prairie planting; Rare (two trees); (#); C = 4; BSUH 11133.

Salicaceae (Willow Family)

Populus deltoides Marshall; Eastern Cottonwood; Floodplain forest east side, along ravines and creeks on west side; Frequent; (#); C = 1; BSUH 11919, 13132.

Salix eriocephala Michx.; Diamond or Heart-Leaved Willow; Around Millie's Pond; Rare; (#); C = 4; BSUH 11746.

Salix exigua Nutt.; SYN: *Salix interior* Rowlee; Sandbar or Narrow-leaf Willow; Along Culmer's Run and around Scott Pond; Infrequent; (#); C = 1; BSUH 11916, 12691.

Salix nigra Marshall; Black Willow; Along Culmer's Run; Rare; C = 3; BSUH 12693.

Salix × *rubens* Schrank; Hybrid Crack Willow; Floodplain woods west of Culmer's Run; Rare; (* #); C = 0; BSUH 11412.

Saxifragaceae (Saxifrage Family)

Heuchera americana L.; American, Common, or Tall Alumroot; Slope woods east of the cattail marsh; Rare; (#); C = 7; BSUH 12509.

Penthorum sedoides L.; Ditch Stonecrop; Drying areas around Scott Pond; Rare, but locally abundant; C = 2; BSUH 12640.

Scrophulariaceae (Figwort Family)

Aureolaria virginica (L.) Pennell; Downy Yellow False Foxglove; Open moist woods north of Iron Gate Road and upland woods east of cattail marsh; Infrequent; (#); C = 8; BSUH 11985.

Chaenorrhinum minus (L.) Lange; Lesser Toadflax, Dwarf Snapdragon; Roadside along auto tour south of Hayes House; Infrequent; (*); C = 0; BSUH 11692.

Chelone glabra L.; White Turtlehead; Cattail marsh and moist meadow north of cattail marsh; Infrequent; C = 7; BSUH 12531.

Penstemon calycosus Small; SYN: *Penstemon laevigatus* Ait. ssp. *calycosus* (Small) Bennett; Eastern Smooth Beard Tongue; Field and woods around Scott Pond; Infrequent, but locally frequent; (#); C = 4; BSUH 12570.

Penstemon digitalis Nutt. ex Sims; Tall White Beard Tongue, Foxglove Beard Tongue; Fields, open woods, and roadside along auto tour south of Hayes House; Frequent, but locally abundant; C = 4; BSUH 11851.

Scrophularia marilandica L.; Eastern or Late Figwort; Along Culmer's Run; Rare; C = 5; BSUH 11986.

Verbascum blattaria L.; Moth Mullein; Fields, especially around Iron Gate Road; Infrequent, but locally abundant; (*); C = 0; BSUH 11707, 12674.

Verbascum thapsus L.; Common or Woolly Mullein; Roadside and along railroad track; Infrequent; (* #); C = 0; BSUH 11951, 12600.

Veronica anagallis-aquatica L.; SYN: *Veronica catenata* Pennell; Water Speedwell; In and around Culmer's Run; Rare; (#); C = 5; BSUH 12632. [Threatened].

Veronica arvensis L.; Corn Speedwell; Roadside, gravel parking lots, fields; Abundant; (* #); C = 0; BSUH 11816, 11917.

Veronica hederifolia L.; Ivy-Leaved Speedwell; Slope woods from Iron Gate Road to the cattail marsh; Abundant; (* #); C = 0; BSUH 11903.

Veronica officinalis L.; Common Speedwell; Woods east of fern garden; Rare; (* #); C = 0; BSUH 11886.

Veronica peregrina L.; Purslane Speedwell, Smooth Purslane; Field south of Iron Gate Road; Rare, but locally frequent; (#); C = 0; BSUH 11915.

Veronica persica Poir.; Bird's-Eye Speedwell; Field near maintenance building, Rare; (* #); C = 0; BSUH 11891.

Simaroubaceae (Quassia Family)

Ailanthus altissima (Miller) Swingle; Tree of Heaven; Woods along railroad track between Research Pond and path to fern garden; Rare; (* #); C = 0; BSUH 11046.

Smilacaceae (Catbrier Family)

Smilax hispida Muhl.; SYN: *Smilax tamnoides* L., *Smilax tamnoides* L. var. *hispida* (Muhl. ex Torr.) Fernald; Bristly Greenbrier or Catbrier; Woods; Abundant; (#); C = 3; BSUH 11780, 12689.

Smilax lasioneura Hook.; SYN: *Smilax herbacea* L. var. *lasioneura* (Small) Rydb.; Common Carrion Flower; Woods' edge; Rare; (%); C = 4; Hayes Arboretum Herbarium.

Solanaceae (Nightshade Family)

Physalis longifolia Nutt. var. *subglabrata* (Mackenzie & Bush) Cronq.; Longleaf or Smooth Ground Cherry; Field east of Nature Center; Rare; (# %); C = 0; Hayes Arboretum Herbarium.

Solanum americanum Mill.; SYN: *Solanum nigrum* L. var. *virginicum* L., *Solanum ptycanthum* Dun.; American Black Nightshade; along Culmer's Run, Around Scott Pond, and along the railroad track; Infrequent; C = 0; BSUH 12543, 12591, 12630.

Solanum carolinense L.; Carolina Horse Nettle; Fields and woods' edge, especially around Scott Pond; Infrequent; (#); C = 0; BSUH 11124.

Solanum dulcamara L.; Bittersweet Nightshade, Climbing Nightshade; Along Culmer's Run near the railroad tract and in the cattail marsh; Rare; (* #); C = 0; BSUH 12633.

Tiliaceae (Linden Family)

Tilia americana L.; American Basswood, American Linden; Woods, especially on the east side; Frequent; C = 5; BSUH 12572, 12703.

Typhaceae (Cattail Family)

Typha angustifolia L.; Narrow-Leaved Cattail; Cattail marsh; Frequent; (* #); C = 0; BSUH 12698.

Typha latifolia L.; Common or Broad-Leaved Cattail; Cattail marsh; Abundant; (#); C = 1; BSUH 11993.

Ulmaceae (Elm Family)

Celtis occidentalis L.; Northern or Common Hackberry; Woods; Abundant; (#); C =3; BSUH 12568.

Ulmus americana L.; White or American Elm; Woods, especially the east side; Abundant; C = 3; BSUH 12650.

Ulmus rubra Muhl.; Slippery or Red Elm; Woods and woods' edge; Frequent; C = 3; BSUH 12576.

Urticaceae (Nettle Family)

Boehmeria cylindrica (L.) Sw.; Small-spike False Nettle; Moist field south of Iron Gate Road, moist meadows and open woods north of Iron Gate Road, and around Scott Pond; Infrequent, but locally frequent; C = 3; BSUH 12639, 12654.

Laportea canadensis (L.) Wedd.; Canadian Wood Nettle; Woods, especially the floodplain woods on east side; Abundant; (#); C = 2; BSUH 12655.

Pilea fontana (Lunell) Rydb.; Bog Clearweed; Cattail marsh; Frequent and in large colonies; (#); C = 5; BSUH 12513, 12532.

Pilea pumila (L.) A. Gray; Canadian Clearweed; Woods, dirt roads, moist meadows; Abundant; C = 2; BSUH 12648,12991.

Valerianaceae (Valerian Family)

Valerianella umbilicata (Sulliv.) A. Wood; Corn Salad; Wet meadow north of cattail marsh; Abundant at this site; C = 5; BSUH 11928.

Verbenaceae (Vervain Family)

Phryma leptostachya L.; American Lopseed; Woods; Frequent; C = 4; BSUH 12565.

Phyla lanceolata (Michx.) Greene; Lance-leaf Fogfruit; Around Scott Pond and in drying areas; Abundant at this site; C = 2; BSUH 11110.

Verbena hastata L.; Common or Blue Vervain; Field; Rare; (%); C = 3; Hayes Arboretum Herbarium.

Verbena stricta Vent.; Hoary Vervain; Field east of Nature Center; Rare; (%); C = 4; Hayes Arboretum Herbarium.

Verbena urticifolia L.; White Vervain; Cattail marsh and moist meadow between Culmer's Run and cattail marsh; Infrequent; C =3; BSUH 11979.

Violaceae (Violet Family)

Viola pubescens Aiton; Yellow Forest Violet, Downy Yellow Violet; Woods; Abundant; (#); C = 5; BSUH 11801.

Viola sororia Willd.; Dooryard Violet, Common or Woolly Blue Violet; Woods and fields; Abundant; (#); C = 1; BSUH 11804.

Viola striata Aiton; Striped Creamy Violet, Common White Violet; Woods and roadside; Infrequent; C = 4; BSUH 11824.

Vitaceae (Grape Family)

Parthenocissus quinquefolia (L.) Planch.; Virginia Creeper, Woodbine; Woods; Abundant; C = 2; BSUH 11908.

Vitis riparia Michx.; Riverbank Grape; Woods; Infrequent; (#); C = 1; BSUH 12609.

Vitis vulpina L.; Frost Grape; Woods; Frequent; (#); C = 3; BSUH 12501.

APPENDIX 2

Ferns and Allies Documented in the Fern Garden, Hayes Arboretum

This list includes ferns documented in the Fern Garden located north of the Spring House. Species are arranged alphabetically, not according to phylogenetic relationships. Nomenclature follows the U.S.D.A. Plant Data Base. Following each species are current synonyms, if any, common names, and the BSUH number.

Adiantum pedatum L.; Northern Maidenhair Fern; BSUH 11247; 12716.

Asplenium platyneuron (L.) Oakes; Ebony Spleenwort; BSUH 11251.

Athyrium filix-femina (L.) Roth.; Lady Fern; BSUH 11235.

Athyrium pycnocarpon (Spreng.) Tidestrom; Glade Fern; BSUH 11289, 12986.

Athyrium thelypterioides (Michx.) Desv.; Silvery Glade Fern; BSUH 11057.

Cystopteris bulbifera (L.) Bernh.; Bulblet Bladder Fern; BSUH 11291.

Cystopteris protrusa (Weatherby) Blasdell; Lowland Bladder Fern; BSUH 12713.

Dryopteris carthusiana (Villars.) H.P. Fuchs; Toothed Wood Fern; BSUH 11233.

Dryopteris goldiana (Hook.) A. Gray; Goldie's Wood Fern; 11253.

Dryopteris marginalis (L.) A. Gray; Marginal Wood Fern; BSUH 11283.

*Equisetum arvense*L.; Common or Field Horsetail; 11896.

Matteuccia struthiopteris (L.) Todaro.; Ostrich Fern; BSUH 11273.

Onoclea sensibilis L.; Sensitive Fern; BSUH 11270, 12549.

Polystichum acrostichoides (Michx.) Schott; Christmas Fern; BSUH 11266.

Thelypteris hexagonoptera (Michx.) Weatherby; Broad or Southern Beech Fern; BSUH 11287.

Thelypteris noveboracensis (L.) Nieuwl.; New York Fern; 11049.

APPENDIX 3

Plants Documented in the Three Prairie Plantings, Hayes Arboretum

This list includes species documented in the three small prairie plantings located south of Hayes House. Species are arranged alphabetically, not according to phylogenetic relationships. Nomenclature follows the U.S.D.A. Plant Data Base. Following each species are current synonyms, if any, common names, and the BSUH number.

Achillea millefolium L.; Common Yarrow; BSUH 12702.

Allium cernuum Roth; Nodding Onion; BSUH 11983.

Andropogon gerardii Vitman; Big Bluestem; BSUH 12670.

Anemone virginiana L.; Tall Anemone, Tall Thimbleweed; 12571.

Ceanothus americanus L.; SYN: *Ceanothus americanus* L. var. *pitcheri* Torr. & Gray; New Jersey Tea; BSUH 11199.

Conoclinium coelestinum (L.) DC.; SYN: *Eupatorium coelestinum* L.; Blue Mistflower; BSUH 12552.

Coreopsis lanceolata L.; Longstalk or Lanceleaf Tickseed; BSUH 12608.

Coreopsis palmata Nutt.; Finger or Stiff Tickseed; BSUH 11127.

Crataegus monogyna Jacq.; Oneseed Hawthorn; BSUH 11361.

Daucus carota L.; Wild Carrot, Queen Anne's Lace; BSUH 12594.

Dichanthelium acuminatum (Sw.) Gould & C.A. Clark var. *fasciculatum* (Torr.) Freckmann; Western Panic Grass, Old-Field Panic Grass; BSUH 11652.

Echinacea pallida (Nutt.) Nutt.; Prairie or Pale Purple Coneflower; BSUH 11207, 13001.

Echinacea purpurea (L.) Moench.; Eastern Purple Coneflower; BSUH 11205.

Erigeron annuus (L.) Pers.; Annual Fleabane, Eastern Daisy Fleabane; BSUH 11857.

Eryngium yuccifolium Michx.; Rattlesnake Master, Button Eryngo; BSUH 11981.

Euphorbia corollata L.; Flowering Spurge; BSUH 12615.

Fragaria virginiana Duchesne; Thick-Leaved Wild Strawberry; BSUH 11598, 12979.

Gaillardia pulchella Foug.; Rosering Blanket Flower, Firewheel; BSUH 12993.

Helianthus occidentalis Riddell; Naked-Stemmed or Few-Leaf Sunflower; BSUH 12620.

Heliopsis helianthoides (L.) Sweet; Sunflower Everlasting, False Sunflower, Smooth Oxeye, BSUH 11141.

Lathyrus latifolius L.; Everlasting or Perennial Pea; BSUH 11332.

Leucanthemum vulgare Lam.; SYN: *Chrysanthemum leucanthemum* L.; Oxeye Daisy; BSUH 12727.

Liatris spicata (L.) Willd.; Sessile or Dense Blazing Star; 11131.

Liatris pycnostachya Michx.; Thick-spike or Prairie Blazing Star; BSUH 11129, 11439.

Liatris ligulistylis (A. Nels.) K. Schum.; Northern Plains or Rocky Mountain Blazing Star; BSUH 12626.

Medicago lupulina L.; Black Medic; BSUH 12605.

Monarda fistulosa L.; Wild Bergamot; BSUH 11982.

Oligoneuron rigidum (L.) Small; SYN: *Solidago rigida* L.; Stiff Goldenrod; BSUH 12621.

Panicum virgatum L.; Switchgrass; BSUH 11769.

Parthenium integrifolium L.; Wild Quinine, Eastern Parthenium; BSUH 11186.

Phleum pratense L.; Timothy; BSUH 12606.

Phlox paniculata L.; Summer or Fall Phlox; BSUH 11333, 12614, 12990.

Physostegia virginiana (L.) Benth.; Obedience, Obedient Plant, False Dragonhead; BSUH 11760.

Plantago lanceolata L.; English or Narrow-Leaf Plantain; BSUH 11875.

Pycnanthemum virginianum (L.) Durand & Jackson; Virginia Mountain Mint; BSUH 11980.

Ratibida pinnata (Vent.) Barnh.; Globular or Gray Headed Coneflower, Pinnate Prairie Coneflower; BSUH 11209.

Rosa setigera Michx.; Climbing Prairie Rose; BSUH 11189, 12598.

Rudbeckia hirta L. var. *pulcherrima* Farw.; Black-eyed Susan; BSUH 11211.

Rudbeckia triloba L.; Three-lobed Coneflower, Brown-eyed Susan; BSUH 11849.

Rudbeckia subtomentosa Pursh; Sweet Coneflower; BSUH 12628.

Rudbeckia fulgida Ait. var. *speciosa* (Wender.) Per-due; Eastern or Orange Coneflower; BSUH 11403.

Ruellia strepens L.; Smooth Ruellia, Limestone Wild Petunia; BSUH 11072, 11192, 11761.

Schizachyrium scoparium (Michx.) Nash; Little Bluestem; BSUH 12554.

Scirpus pendulus Muhl.; Red or Rufous Bulrush; BSUH 11876.

Scutellaria incana Biehler; Hoary Skullcap; BSUH 11727, 12987.

Silphium laciniatum L.; Compass Plant; BSUH 11365, 12671.

Silphium terebinthinaceum Jacq.; Basal-leaved or Prairie Rosinweed, Prairie Dock; BSUH 11215, 11336.

Sisyrinchium angustifolium Mill.; Stout or Narrow-Leaf Blue-Eyed Grass; BSUH 11954, 12995.

Solidago nemoralis Aiton; Gray Goldenrod; BSUH 11757, 12507.

Sorghastrum nutans (L.) Nash; Indian Grass; BSUH 12619.

Symphyotrichum novae-angliae (L.) Nesom; SYN: *Aster novae-angliae* L.; New England Aster; BSUH 11745, 11759, 12553.

Thaspium trifoliatum (L.) A. Gray; Smooth or Purple Meadow Parsnip; BSUH 11197.

Toxicodendron radicans (L.) Kuntze var. *negundo* (Greene) Reveal; Common or Eastern Poison Ivy; BSUH 11860.

Tradescantia ohiensis Raf.; Smooth or Ohio Spiderwort, Bluejacket; BSUH 12992.

Trifolium pratense L.; Red Clover; BSUH 11393.

Veronicastrum virginicum (L.) Farw.; Culver's Root; BSUH 11202.

Vitis riparia Michx.; Riverbank Grape; BSUH 12609.

Zizia aurea (L.) Koch; Common Golden Alexanders, Golden Zizia; BSUH 12678, 13000.

APPENDIX 4

Display/Educational Plants Planted (Not Naturalized), Hayes Arboretum

This list includes species that have been planted at various sites in the arboretum for education or display. Species are arranged alphabetically, not according to phylogenetic relationships. Nomenclature follows the U.S.D.A. Plant Data Base. Following each species are current synonyms, if any, common names, and the BSUH number.

Aesculus flava Aiton; Sweet or Yellow Buckeye; BSUH 11866.

Amelanchier arborea (Michx. f.) Fernald; Downy or Common Serviceberry; BSUH 11830.

Buddleja davidii Franch.; Orange-eye Butterfly Bush; BSUH 11725.

Carya illinoinensis (Wengenh.) K. Koch; Pecan; BSUH 12517.

Cimicifuga racemosa (L.) Nutt.; Black Cohosh, Black Bugbane; BSUH 11978.

Corylus americana Walt.; American Hazelnut; BSUH 12616.

Dasiphora floribunda (Pursh) Kartesz; SYN: *Potentilla fruticosa* L.; Shrubby Five-Finger, Shrubby Cinquifoil; BSUH 11184.

Dodecatheon meadia L.; Eastern Shooting Star; BSUH 12710.

Fagus sylvatica "Asplenifolia" L.; European Cutleaf Beech; BSUH 12523.

Forsythia × *intermedia* Zabel; Golden Bell, Forsythia; BSUH 11893.

Gleditsia triacanthus f. *inermis* (L.) Zabel; Thornless Honey Locust; BSUH 12686.

Hibiscus syriacus L.; Rose of Sharon; BSUH 11847.

Hypericum prolificum L.; Shrubby St. John's Wort; BSUH 11237.

Liquidambar styraciflua L.; Sweetgum; BSUH 12707.

Magnolia acuminata (L.) L.; Cucumber Tree; BSUH 12708.

Metasequoia glyptostroboides Hu & Cheng; Dawn Redwood; BSUH 12977.

Monarda didyma L.; Oswego Tea, Scarlet Bee Balm; BSUH 12524.

Narcissus pseudonarcissus L.; Daffodil; BSUH 11811.

Physocarpus opulifolius (L.) Maxim.; Common Ninebark; BSUH 12704.

Picea pungens Engelm.; Blue Spruce; BSUH 11913.

Picea abies (L.) Karst.; Norway Spruce; BSUH 12980.

Pinus strobus L.; Eastern White Pine; BSUH 11905.

Pinus resinosa Soland.; Red Pine; BSUH 12528.

Pinus nigra Arnold; Austrian Pine; 11942.

Pyracantha coccinea (Medik.) Roem.; Scarlet Firethorn; BSUH 11432, 12667.

Quercus bicolor Willd.; Swamp White Oak; BSUH 12994.

Quercus coccinea Muenchh.; Scarlet Oak; BSUH 11716.

Rhus aromatica Aiton; Squaw Bush, Fragrant Sumac; BSUH 12550.

Rhus copallinum L.; Shining or Flameleaf Sumac; BSUH 11770, 12544.

Rhus hirta (L.) Sudworth; SYN: *Rhus typhina* L.; Staghorn Sumac; BSUH 11304.

Salix cinerea L.; Large Gray Willow; BSUH 11328.

Salix discolor Muhl.; Pussy Willow; BSUH 11363.

Spiraea × *vanhouttei* (Briot) Carr.; Vanhoutte Spirea, Bridal Wreath; BSUH 12613.

Spiraea alba Du Roi; White Meadowsweet; BSUH 12617.

Taxodium distichum (L.) Rich.; Bald Cypress; BSUH 12730, 12978.

Tsuga canadensis (L.) Carr.; Eastern Hemlock; BSUH 11067.

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A SYNOPSIS OF INSECT ACTIVITY IN INDIANA DURING 2005

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ABSTRACT. Most agricultural insect populations remained unchanged during 2005 when compared to previous years. The first generation European corn borer population was negligible, but numbers of the second generation were higher than expected. Populations of western corn rootworm variants declined when compared to the previous year. Soybean aphid feeding exceeded damage thresholds throughout many parts of the state during 2005. Springtime honey production was high considering the varroa mite infestations of the winter months. Summer heat following the August honey harvest stressed the survival of many hives into the fall and winter. Indiana experienced a number of exotic invasive insects of regulatory concern in 2005. Granulate ambrosia beetles and common pine shoot beetles expanded their ranges in Indiana during 2005. Emerald ash borers were found for the first time in LaGrange, Steuben, Adams, and Randolph counties. Overall, the insect damage to fruits and vegetables was normal or slightly below normal throughout most of the state. The number of complaints resulting from carpenter bee activity around homes was higher, but the number of swarming termite complaints was lower than in most years. Numbers of mosquito and tick reports were low. Scale insects in ornamental plantings were generally more common during 2005, as were the common web-making caterpillars (fall webworm, eastern tent caterpillar, and mimosa webworm). Inquiries concerning wood-boring beetles rose again during 2005, but it was difficult to determine whether this was due to increased beetle activity or due to recent media campaigns regarding the emerald ash borer. Scavenger and moisture-related insects in stored grain were common during 2005. For the second year in a row, reports of damage due to turfgrass insect pests were uncommonly few.

Keywords: Granulate ambrosia beetle, common pine shoot beetle, emerald ash borer, insect activity, ornamental pests

A summary of arthropod activity in Indiana during 2005 was compiled based on informal surveys and anecdotal reports by professional entomologists representing several areas of expertise throughout the state. This synopsis has a history of publication in the *Proceedings* of the Indiana Academy of Sciences as early as the 1970s (Meyer 1984) and provides a valuable source for determining the fluctuations of insect populations. General descriptions of insect activity are compared and contrasted with previous years to document insect population trends within the year as well as over multiple years and to determine weather/insect relationship (Gibb & Bledsoe 1990; Gibb 1992). In this study, we report on activity of exotic pest invasions, agriculturally economic pests, nuisance and health-related pests and other urban structural and landscape arthropods.

General weather overview.—In 2005, for the second year in a row, Indiana experienced a comparatively mild winter, posting a stretch of unusually warm temperatures during late winter in most locations. Across the state, 2–8 times the average amount of wintertime precipitation was received. A cold snap returned in March; but even so, accumulated growing degree-days by springtime were higher than normal (National Agricultural Statistics Service 2005). Spring suddenly appeared in early April with rapidly warming air and soil temperatures resulting in significant agricultural activity (planting crops), particularly in northern counties. The spring-like conditions were replaced by cold and damp weather during the last two weeks of the month and into the first few days of May. Scattered snow showers were common across northern Indiana on 2

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May. May warmed slowly and agricultural crops struggled to emerge. Corn replanting was common in northern counties. The remainder of the growing season tended to be dry and warm with the temperature exceeding 32 °C on many days. Precipitation was scattered, and some areas received sufficient rain while other areas were exceptionally dry. Above-normal temperatures extended into the fall of 2005, breaking several records in September, October and November. The first light frosts occurred statewide during the last few days of October and the first days of November. Fall vegetation was killed as the first hard freeze of the season occurred on 16–17 November. Bitter cold and snow in northern counties came early and suddenly in December and persisted until the last week of the month.

AGRICULTURAL INSECTS

Field crop insects.—First stage western corn rootworm larvae were initially detected in Tippecanoe County in corn roots on 31 May 2005. It is probable that egg hatch began 2–3 days earlier in central Indiana and a week earlier in southern counties. Corn rootworm adults were first detected in emergence traps in northwest Indiana between 17–24 June. An annual statewide survey conducted in late July and early August indicated that numbers of the adult variant western corn rootworm beetle (*Diabrotica virgifera virgifera* LeConte) had generally declined from populations seen in 2004 (Pest & Crop Newsletter 2005).

Low incidence of first generation European corn borer (*Ostrinia nubilalis* Hübner) infestations followed a pattern that has persisted for the past few years (Pierce et al. 2005). However, second generation larvae were more abundant, and damage was slightly more widespread than has been noted in recent years. The cyclic nature of the soybean aphid (*Aphis glycines* Matsumura) populations (Pest & Crop Newsletter 2005) was once again apparent. Economic damage thresholds by soybean aphids were exceeded in 2005 after very minimal damage in 2004 (Pierce et al. 2005). As a result, 70% of soybeans in northeast Indiana received at least one insecticide treatment, compared to 10% the year previous year. Although as much as 50% of the soybeans in northwest Indiana was treated, many fields probably did not reach economic injury levels.

A statewide soybean survey (Pest & Crop Newsletter 2005) conducted during mid-summer indicated that second generation bean leaf beetle (*Certoma trifurcata* (Forster)) continued its trend of generally low incidence. Highest populations were detected in west central and northwest counties. However, these populations were only a small fraction of the size of those observed during 1999 in northeast and east central counties.

Japanese beetle (*Popillia japonica* Newman) populations in field crops continued a downward trend in 2005, representing roughly one-quarter of the numbers observed in the west central and southeastern counties during 2000 (Pest & Crop Newsletter 2005). Greatest 2005 populations were found in central and east central counties.

Honey bees.—Varroa mite (*Varroa destructor* Anderson & Trueman) was found to be widespread across the state, resulting in the loss of an estimated 50% of honey bee hives during the winter of 2004/05. This was followed by an unexpectedly large honey yield in the late spring of 2005 in many areas, and many Indiana beekeepers reported record honey harvests. The biggest problem for most Indiana beekeepers was a lack of rain in the late summer, leading to the need to artificially feed the bees syrup to avoid starvation. Some beekeepers harvested the honey at the beginning of August, just before weather conditions became most severe. This resulted in a lack of food reserves in the hive during a time when nectar sources were also in limited supply due to the weather. The resulting bee malnutrition increased susceptibility to mite infestations throughout the state.

EXOTIC INVASIVE INSECTS

Old world bollworm.—Old world bollworm (*Helicoverpa armigera* (Hübner)) surveys were initiated in 2005 under the Indiana Cooperative Agricultural Pest Survey (CAPS) program (Old World Bollworm Survey 2005). This bollworm is a highly polyphagous pest of many economically significant crops in Africa, Asia, Australia, and Europe. It feeds on over 180 cultivated and wild species, including several important Indiana crops, such as corn, soybeans, alfalfa, and tomatoes. About 5,900,000 acres (2,387,697 ha) of corn, 5,800,000 million acres (2,347,227 ha) of soybeans, 62,000 acres (25,091 ha) of alfalfa, and 7000 acres (2832 ha) of tomatoes are grown in Indiana each season (National Agricultural Statistics Service 2005). Furthermore, approximately 49% of the continental U.S. provides suitable habitat for this pest (Old World Bollworm Survey 2005). No specimens were collected during the survey in 2005, but surveys will continue during 2006.

Emerald ash borer.—In 2005, trap trees were placed on a 3.25 km grid in 15 counties in northern Indiana to detect populations of emerald ash borer, *Agrilus planipennis* (Fairmaire). Counties surveyed included Lake, Porter, LaPorte, St. Joseph, Elkhart, LaGrange, Nobel, Whitley, Steuben, DeKalb, Allen, Randolph, northern Starke, northern Marshall, and northern Kosciusko. There were 1300 trap trees designated in April and set during May through mid-June. Inspection of the trap trees began the third week in September and ended on 31 October 2005. Of the 1300 proposed trap trees, 1056 trees were set and examined. The first adult emerald ash borer of the season was found emerging from a log in Shipshewana (LaGrange County) on 11 May 2005. This emergence came about a week and a half earlier than in 2004 (Pierce et al. 2005). A visual survey for emerald ash borer, including 860 campgrounds, 386 nurseries (grower), 807 nurseries (retailers), 186 saw mills, and 119 organic dumps was conducted in 2005.

LaGrange County: An emerald ash borer-positive site was reported in Clay Township in LaGrange County, approximately 2 km north of the Clearspring Township line. A new positive site was discovered 1.5 km north of the town of Scott, north of the Pigeon River. The positive trap tree was heavily infested. There are also standing dead ash trees in the area. This site is in Van Buren Township, approximately 6.5 km from the Shipshewana regulatory cuts last year, placing it solidly within the Pigeon River riparian corridor.

Steuben County: Emerald ash borer was detected in a trap tree in Steuben County, near the southeast corner of Lake George in Steuben County, 0.4 km south of the Michigan state line.

Adams County: Emerald ash borer was confirmed at a location in Adams County on 12 October 2005. As a result of the confirmed discovery, the DNR quarantined Root and Washington townships. The Decatur city forester reported finding larvae and an adult on an ash tree. Identifications were confirmed by the U. S. Department of Agriculture. The Decatur site is approximately 14.5 km west of the Ohio border and 32 km south of Fort Wayne. At the Decatur site, DNR personnel conducted a delimiting survey around the new find. To date, live larvae have been removed from 19 of the 77 trees involved in the delimiting survey.

Randolph County: The emerald ash borer was confirmed at a location in Randolph County on 11 November 2005 resulting in the quarantine of White River Township. The U.S. Department of Agriculture confirmed that larvae have been discovered in about seven trees that follow a small drainage ditch about one kilometer from a site where Michigan nursery stock was introduced several years ago, although another source in the area is possible. The site includes the town of Winchester. Indiana DNR personnel and others conducted a delimiting survey of the area around the new find. To date, of the 40 trap trees in Randolph County, larvae have been found in 10 trees.

Gypsy moth.—The 2005 Cooperative Gypsy Moth Survey completed its 18th year of statewide surveys for the European gypsy moth, *Lymantria dispar* Linnaeus. These surveys are part of the Slow-The-Spread (STS) Program and incorporate the STS protocol for their design and operations. Under this protocol, Indiana is divided into three zones: the STS Evaluation Zone, the STS Action Zone, and the State Area. The survey design uses fixed 3 km, fixed 2 km, and rotating 3 km grids, respectively, for the three zones (Slow-The-Spread of the Gypsy Moth Project 2005). Across all zones, the survey set 13,231 detection and 3127 intensive traps, all referenced by GPS. The survey detected 18,222 moths from 44 counties, ranging from 1–4323 moths per county. This is a 2× increase from the 2004 total moth catch of 9034 and falls between the catch totals for 2002 and 2003 (15,569 & 23,090, respectively) (European Gypsy Moth in Indiana 2005).

The results of the 2005 survey found that the majority of the moth catch came in the Action Zone. The Evaluation Zone, which includes the quarantined counties of Steuben, LaGrange, Elkhart, Noble, Allen, and DeKalb, detected 32.8% of the moths (5980 of 18,222). The northern third of the state falls in the Action Zone, which is below the Evaluation Zone under STS protocol. The Action Zone detected 51.0% of the moth catch (9290 of 18,222). The majority of the moth catch in this zone was located in the eastern part of the state adjacent to the Evaluation Zone. The state survey detected 16.2% of the moths (2953 of 18,222). The Scott County survey included an intensive delimit around a known population which inflated the overall statewide moth capture totals. All positive traps in the state zone are delimited the following year.

Treatments to eradicate and to Slow-The-Spread of gypsy moth were conducted on 33 sites in 11 counties during 2005. Fifteen sites, totaling 3292 ha were treated with *Btk* (*Bacillus thuringiensis kurstaki*) at 12 BIU/ha/application. Eleven sites were treated with two applications of *Btk* (2566 ha). Four sites treated with one *Btk* application (726 ha). Nine sites were ground treated with one application of *Btk* at 30 BIUs. Five sites totaling 1762 ha and four sites totaling 4206 ha received one application of pheromone flakes for mating disruption at 6 and 15 gm, respectively, in June. Delimit surveys to monitor treatment success found that one *Btk* site failed (Arcola) and three had only partial success (Bremen South, Cobb's Corner and Leesburg). This was most likely due to small block sizes and timing of treatments (ground treatments were performed later in the season). These sites have been reevaluated and were treated in 2006.

The aerial survey of the five northeastern counties in the Evaluation Zone and the other counties with treatment sites in the Action Zone did not detect defoliation. Some defoliation was observed from the ground in Scott County, where a sizable population of moths was found. This site had an eradication treatment in 2006.

The moth lines projected for 2005 have remained fairly static across the state with no significant change from the moth lines of 2003 and 2004. The survey and program to manage gypsy moth in Indiana continues to compress the distance between moth lines, thus slowing the spread of gypsy moth in Indiana. Since the 1972 survey, 268,994 moths have been caught in 90 of Indiana's 92 counties. No new county records were established in 2005.

In 2005, USDA APHIS PPQ officers continued the Indiana Asian Gypsy Moth survey program. The survey provides early detection of Asian gypsy moth (*Lymantria dispar dispar* (Linnaeus)) introductions resulting from the international movement of ships and cargo. Ten milk carton traps were placed in Porter County at the Port of Indiana (Burns Harbor) on 30 June 2005 and checked on a bi-weekly basis. Traps were removed on 9 September 2005. No specimens were detected during the course of this survey.

The Asian gypsy moth has more than 250 known host plants but prefers oak. Other hosts include larch, poplar, alder, willow, and some evergreens. The Asian gypsy moth is of great concern due to its potential for rapid establishment and spread. The pest can cause severe damage to trees over a large area; heavy infestations may result in repeated and complete defoliation of trees. Defoliation can kill trees directly or reduce vigor, leading to secondary pest outbreaks, also resulting in tree death. The ability of Asian gypsy moth females to fly long distances (up to 40 km) makes it probable that the Asian gypsy moth could quickly infest and spread throughout the United States. As well as having direct economic effects on commercial forestry and horticulture, Asian gypsy moth has the potential to reduce the aesthetic, recreational, and biodiversity values of park rangelands and wilderness areas.

Granulate ambrosia beetle.—In 2005, granulate ambrosia beetles (a.k.a. Asian ambrosia beetle) (*Xylosandrus crassiusculus* (Motschulsky)), were collected in 25 additional counties during Indiana Department of Natural Resources (IDNR) nursery inspections and in Hot Zone survey traps in Indiana. Those counties are: Brown, Clark, Clay, Dubois, Fountain, Henry, Jennings, Lawrence, Marion, Montgomery, Parke, Perry, Porter, Posey, Putnam, Randolph, Spencer, Sullivan, Tippecanoe, Vanderburgh, Vigo, Wabash, Warren, Wayne, and White. In 2004, Asian ambrosia beetles occurred in six counties in Indiana: Bartholomew, Boone, Hendricks, Jackson, Johnson, and Monroe.

The granulate ambrosia beetle is capable of breeding in a wide variety of hosts. Known hosts in the U.S. include azalea, Bradford pear, Chinese elm, dogwood, fig, golden rain tree, magnolia, ornamental cherry, peach, pecan, persimmon, plum, redbud, red maple, Shumard oak, stryax, sweetgum, and sweet potato. This beetle, a pest of woody ornamental, fruit, and nut trees throughout Indiana, can cause significant damage in nursery and orchard settings. It spreads by natural distribution and shipment of contaminated plant material. No regulatory action has been taken for this pest. Females bore into plant trunks and inoculate the tunnel with fungal spores. The females then produce a brood. The larvae and the females feed on the fungus, not the host. Heavily-infested plants usually die from the inoculated fungus or a secondary disease.

Common pine shoot beetle.—Common pine shoot beetle (*Tomicus piniperda* (Linnaeus)) was first reported in the U.S. in 1992. These beetles require live or very recently killed pine trees in order to feed and reproduce. They do not harm sawed timber. The beetles can kill already stressed trees and may weaken and kill healthy trees when populations get very high. On 14 January 2005, USDA APHIS PPQ officers set 80 delimiting traps for common pine shoot beetle in 10 southern counties in Indiana (eight traps per county). Lindgren funnel traps, baited with alpha-pinene were used. Surveyed counties included: Clay, Dearborn, Greene, Jackson, Jefferson, Lawrence, Ohio, Scott, Sullivan, and Switzerland. The traps were placed in locations with high concentrations of potential host plants and checked on a bi-weekly basis. Dearborn County was regulated for common pine shoot beetle due to the confirmed find, on 20 May, of a single common pine shoot beetle.

Bark and wood-boring beetles.—A "Hot Zone" survey between the USDA APHIS PPQ and the Indiana CAPS program targeted invasive Solid Wood Packing Material (SWPM) pests at 51 sites continued in Indiana in 2005 (Solid Wood Packing Material Survey 2005). No pests targeted in the SWPM survey were collected even though traps were set at sites with high risk for the introduction of exotic invasive bark, jewel, and wood-boring beetles. Twenty exotic invasive bark, jewel, and wood-boring beetles that threaten Indiana natural resources were targeted in this survey which will continue in 2006 (Table 1).

Table 1.—List of target bark, jewel, and wood-boring beetles surveyed for in the "Hot Zone" survey in 2005.

Scientific Name:	Common Name:
Agrilus planipennis Fairmaire	Emerald ash borer
Anoplophora chinensis (Forster)	Citrus longhorned beetle
Anolplophora glabripennis (Motschulsky)	Asian longhorned beetle
Callidiellum rufipenne (Motschulsky)	Small Japanese cedar longhorned beetle
Chlorophorus annularis Fabricius	Bamboo/Tiger bamboo longhorned beetle
Hesperophanes (Trichoferus) campestris (Faldermann)	Chinese longhorned beetle
Hylurgops (Hylurgus) palliatus Gyllenhal	Exotic bark beetle
Hylurgus ligniperda (Fabricius)	Golden-haired bark beetle
Ips sexdentatus (Boerner)	Six-spined engraver beetle
Ips typographus (Linneaus)	European spruce bark beetle
Monochamus alternatus Hope	Japanese pine sawyer beetle
Orthotomicus erosus (Wollaston)	Mediterranean pine engraver beetle
Pityogenes chalcographus (Linnaeus)	Six-toothed spruce engraver
Tetropium castaneum Linnaeus	Black spruce beetle
Tetropium fuscum (Fabricius)	Brown spruce longhorned beetle
Tomicus minor (Hartig)	Lesser pine shoot beetle
Tomicus piniperda (Linnaeus)	Common pine shoot beetle
Trypodendron domesticum (Linnaeus)	European hardwood ambrosia beetle
Xyleborus spp.	Exotic bark beetles
Xylotrechus spp.	Exotic longhorned beetles

The purpose of this survey, conducted at selected businesses and warehouses in Indiana that receive solid wood packing material, is to document pest movement of invasive bark and wood-boring beetles into Indiana. This activity is implemented in warehouses in conjunction with USDA APHIS PPQ officers. In Indiana, over 4.3 million acres (1.7 million ha) of high-quality hardwood forests support an industry which employs 47,000 Hoosiers. These forests are at risk of attack by exotic invasive bark and wood-boring beetles (Solid Wood Packing Material Survey 2005). The Indiana CAPS program in conjunction with USDA APHIS PPQ seeks to conduct a cooperative agricultural pest survey program that is expected to result in the detection or absence of exotic invasive bark and wood-boring beetles in Indiana via solid wood packing material. Early detection and outreach education are the goals of this survey (Solid Wood Packing Material Survey 2005).

In conjunction with Indiana USDA APHIS PPQ Officers and the Indiana CAPS program, 50 sites were selected for survey following guidelines from the Exotic Wood Borer Bark Beetle Field manual 2004 (Exotic Wood Borer Bark Beetle National Survey Field Manual 2004). The Indiana CAPS program was responsible for conducting survey at seven sites in central Indiana. Three Lindgren funnel traps were placed and serviced in each of the seven selected sites. Traps contained one of the following lures: UHR ethanol, UHR ethanol/alpha-pinene, and Ips lure. Traps were placed in mid-March and serviced bi-weekly until mid-October (approximately 30 sampling dates). Visual surveys for invasive wood-boring beetles and metallic wood-boring beetles occurred bi-weekly.

HOME, YARD, AND GARDEN INSECTS

Fruit and vegetable insects.—Overall, insect and mite activity in fruits and vegetables was normal or slightly below normal throughout most of the state during 2005 (Vegetable Crops Hotline 2005). No notable outbreaks were reported. Even though the springtime temperatures were higher than normal and the development of insects and plants was accelerated, no significant mite outbreaks occurred. Codling moth (*Cydia pomonella* (Linnaeus)) numbers were lower than normal. The number of Japanese beetles in fruits varied with geographical location. Asian lady beetles (*Harmonia axyridis* (Pallas)) in grapes and apples were higher compared to 2004 (Pierce et al. 2005) but not as high as they were during 2003.

First generation corn borer (*Ostrinia nubilalis* Hübner) populations were an insignificant threat to vegetables as well as row crops. *Bt* corn may be the cause of this decline. The only vegetable pest that caused real concern during 2005 was the corn earworm (*Heliothis zea* (Boddie)). This pest occurred in high numbers on late sweet corn and tomatoes (tomato fruitworm) possibly as a result of a storm condition that stalled over the state during the dispersal period of the pest. The development of insecticidal resistance also may be contributing to the build-up of this pest.

Household insects.—Major changes in control techniques and the availability of new control options, primarily termite baiting systems, have resulted in many general termite calls to the department in recent years. In the year 2005, numbers of questions regarding termite control remained consistent with the past few years even though many professional pest managers reported that their termite control business was down this year. Eastern subterranean termite (*Reticulitermes flavipes* (Kollar)) swarming behavior observed by homeowners is the most common trigger for a call to professional pest control. Unseasonably warm temperatures at the end of winter in 2005 and into the early spring may have initiated an early swarming behavior that was quickly interrupted by the onset of very cool temperatures again. Termite experts at Purdue University have noted that the termite-swarming season tends to be more persistent (prolonged) when consistently warm temperatures follow cold temperatures during February and March.

Typically, powder-post bostrichid beetles (Bostrichidae) tend to be an under-reported pest group. Most Plant & Pest Diagnostic Laboratory (P&PDL) inquiries about bostrichids come from log home owners or people using barn siding in homes. These beetles and their damage often go undetected for long periods of time in crawl spaces, basements, or attics, but are readily seen by log home owners and people using old wood or ornamental "pieces" in their homes. Weather tends to have less of an effect on these insects than it does on swarming or social insects. The number of complaints about powder-post beetles in newly constructed homes increased in 2005. It appears that the hardwood trim, baseboards, and cabinetry have been infested prior to installation.

Carpenter ants (especially *Camponotus pennsylvanicus* (De Geer)) and carpenter bees (*Xylocopa virginica* (Linnaeus)) have been reported more frequently because more and more neighborhoods have maturing trees and structural timbers that attract these insects and serve as nesting habitats for them. Calls regarding these pests increased again in 2005 following a trend of slightly increasing complaints over the last few years.

Landscape and ornamental insects.—Reports from the Plant & Pest Diagnostic Laboratory (P&PDL) concerning ornamental and public health-related pest submissions indicated that overall pest activity was average with a few exceptions (P&PDL newsletter 2005). The numbers of armored and soft scales, including the euonymous scale, (*Unaspis euonymi* (Comstock)), were generally elevated during 2005. Japanese beetle emerged during the second week of June in central Indiana, approximately one week earlier than usual. Adult feeding damage seemed to be higher when compared to the previous year.

Elm flea weevils (*Orchestes alni* (Linnaeus)) were first detected in the U.S. during 2000 and first found in Indiana during 2003. These insects mine the leaves of elm trees and seem to be occupying the niche of the elm leaf beetles that were a serious problem a few years ago but that have nearly disappeared in recent years.

Reports of mimosa webworm (*Homadaula anisocentra* Meyrick) fall webworm, (*Hyphantria cunea* (Drury) and eastern tent caterpillar (*Malacosoma americanum* Fabricius) were more frequent during 2005. Evergreen bagworms (*Thyridopteryx ephemeraeformis* (Haworth) continued to be quite prevalent around the state during 2005, as they have been during the last 2–3 years.

Spider mite (Tetranychidae) infestations on ornamental plants remained higher than most years but not as high as in 2004 (Pierce et al. 2005).

Numbers of bark beetles and wood-borers generally increased during 2005 over last year. Dead or stressed trees from the prior year's drought may be providing unlimited food and habitat resources to these insects. The news media blitz regarding exotic wood borers and their potential damage has also undoubtedly caused an increase in the number of bark beetles and wood borer samples submitted to the P&PDL, as well as an increase in questions to the department of entomology.

Public health pests.—The rainfall pattern and limited amount of rain during summer of 2005 in Indiana resulted in relatively few nuisance mosquitoes and vector mosquitoes. Indiana specialists reported fewer habitats that supported development of larvae of floodwater mosquitoes during 2005 when compared to previous years. In most cases, streams did not overflow and rain water that collected in soil depressions dried up before eggs of *Aedes* and *Psorophora* mosquitoes hatched. Survey of habitats that supported the development of *Culex* mosquito larvae in recent years either were dry or didn't have larvae throughout most of the summer. The number of West Nile virus incidences likewise decreased again in Indiana during 2005. Collections of both adult nuisance and vector mosquitoes were relatively very low throughout the summer. The number of nuisance mosquito complaints to the Department was down this year, which validated this finding. The numbers of tick-related complaints were also comparatively low during 2005.

Stored food and grain insects.—An increase in the number of complaints involving scavenger insects such as larder beetles, (*Dermestes lardarius* Linnaeus), and other carpet beetles (*Dermestes* sp.) was noted in 2005. Some infestations may relate to unsanitary conditions, but others seem to stem from an increase of shipments containing infested materials. Moisture-related insects such as psocids (Psocidae), springtails (*Orchesella* sp.), foreign grain beetles (*Ahasverus advena* (Waltl)), and flat grain beetles (*Chryptolestes pusillus* (Schonherr)) were more common in 2005.

Turfgrass insects.—Turfgrass insects were infrequently reported as pests during 2005 (Turf Tips 2005). Japanese beetle populations were spotty in urban areas. Some areas reported locally heavy populations and damage to ornamental plants due to the adult beetle feeding, while others reported a conspicuous lack of Japanese beetles in 2005. Grub populations generally followed this spotty distribution as well. Some turfgrass areas in the state were damaged by grubs. Many were treated preventively.

Billbugs (*Sphenophorus parvulus* Gyllenhal) continued to be common during survey work in turfgrass, but were under-reported as a turfgrass pest.

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INSECTICIDE RESIDUES IN BATS AND GUANO FROM INDIANA

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ABSTRACT. Over recent decades, numerous species of bats have been declining, but the causes are not well understood. One of the causes often mentioned is that of environmental toxicants. Feeding on insects makes insectivorous bats more likely to be exposed to insecticides. We sent nine bats (5 Indiana myotis, *Myotis sodalis*, and 4 northern myotis, *Myotis septentrionalis*) through U.S. Fish & Wildlife Service (USF&W) sources to be tested for toxicants. Three of these proved to have organophosphate (OP) insecticide residues: chlorpyrifos (0.18 μg/g), diazinon (0.034 μg/g), and methyl parathion (0.015 μg/g). Chlorpyrifos was also detected in all six dead Indiana myotis found during the USF&W Service biennial mid-winter hibernacula surveys in Ray's and Wyandotte Caves, both important Indiana myotis hibernacula. Chlorpyrifos or dichlorvos (another OP) was found in Indiana myotis guano from all four caves sampled (Wyandotte, Coon, Grotto and Ray's). These data are particularly surprising since OP insecticides are thought to have little bioaccumulation in living tissues or in food chains. Their presence in a tissue sample is indicative of exposure shortly before death (O'Shea & Clark 2002; Hill 1989, 1995). Even though exposure to low doses might not be the primary cause of mortality, such exposure could impair echolocation, coordination and response time which, in turn, could lead to significant injuries and death of bats in the field (O'Shea & Clark 2002). Presence of OPs in bat guano from caves may suggest insecticide application near these hibernacula and constitutes clear evidence of oral exposure through persistence of toxicants in water or through the food chain.

Keywords: Cholinesterase inhibition, organophosphate insecticides, bats, residues

Apart from being an important part of the ecosystem, insectivorous bats are the main predators on nocturnal insects; and they consume numerous agricultural pest insects (Whitaker 1995; Lee & McCracken 2005). Nevertheless, many North American bats, including the federally-endangered Indiana myotis (*Myotis sodalis*), are declining. The total population of the Indiana myotis was estimated to be approximately 380,000 bats in 2001, down from an estimated 880,000 bats in 1960 (Clawson 2002). Whitaker et al. (2002) indicated that the evening bat (*Nycticeius humeralis*), the little brown myotis (*Myotis lucifugus*), the eastern red bat (*Lasiurus borealis*) and the hoary bat (*Lasiurus cinereus*) are declining in Indiana. Habitat decrease and vandalism in hibernacula are some of the reasons bats decline. Another reason may be environmental contaminants such as pesticides. Several organochlorine pesticides have been implicated in free-ranging bat mortality (Clark et al. 1978, 1980; Clark 1981). However, it is unknown how widespread these types of incidents may have been or what relation they may have had to range-wide bat populations. It is even less clear what effects present-day insecticides might have on bats. The decline of insectivorous bats could be partially related to pesticides. In addition to direct toxicity, there could be a decrease in food availability, sub-lethal toxic effects, or perhaps both. Regardless, the decline of insectivorous bats is not beneficial to agricultural pest managers.

The cholinesterase-inhibiting insecticides (organophosphates and carbamates) are widely used in Indiana, according to the National Pesticide Information Retrieval System (NPIRS) List of Pesticides Registered in Indiana for 2006. NPIRS contains federal pesticide registration data from the U.S. Environmental Protection Agency (EPA) and from state pesticide registration data. These insecticides are highly toxic but not very fat soluble, and were not previously reported to accumulate in living tissues (O'Shea & Clark 2002; Hill 1995) or in food chains (Schmidt et al. 2002). Hoffman et al. (2001) describe organophosphates (OPs) and carbamates as inhibitors of the enzyme cholinesterase (ChE). ChE hydrolyzes the neurotransmitter acetylcholine in nervous tissue. Clinical signs of toxicity include salivation, lacrimation, urination, defecation, tremor, convulsions and eventually paralysis (Grue et al. 1997). Death occurs due to respiratory failure and asphyxia (Wilkinson 1976). In addition to neurotoxic effects, anti-ChE compounds have been shown to exert effects on endocrine and immune function in higher vertebrates (Hoffman et al. 2001). Grue et al. (1997) reviewed the sub-lethal effects of ChE inhibitors on captive small mammals and birds. These include impaired thermoregulation (i.e., pronounced hypothermia, with normal body temperature usually resumed within 24 hours), reduced food consumption, and reproductive problems caused by impaired sexual behavior and changes in levels of reproductive hormones (i.e., reduced luteinizing hormone levels).

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Alterations of thermoregulatory ability have potentially serious consequences to bats due to their metabolic complexities. Gordon (1993) suggested that hypothermia is the natural response of mammals in order to minimize the effects of toxicants. Bats often enter into torpor to conserve energy when demands are high and energy resources are low (Kurta et al. 1989). How anti-ChE compounds might affect this poorly-understood physiological response is unknown. Reduction in food consumption might also reduce reproductive success, pup or nestling weight, and survival of offspring in mammals and birds (Grue et al. 1997; Hill 1995). Reduced reproductive success, leading to fewer young, would be particularly bad for bats because of their low reproductive rate. Most species of bats in Indiana produce only one or two offspring per year (Whitaker & Hamilton 1998). Low reproductive rate dictates slow recovery of affected populations (Clark & Shore 2001).

McFarland (1998) analyzed ChE activity in brains of little brown myotis and northern myotis (*Myotis septentrionalis*) from agricultural sites in northern Missouri during summer and found brain ChE inhibition in some of the bats. He suggested that these bats may be exposed to sub-lethal levels of OP and/or carbamate insecticides. Chlorpyrifos was detected at low levels in nearly every bat collected and analyzed on Fort Leonard Wood, Missouri during 2002–2003 (BHE 2004, 2005). Land (2001) was the first to report detections of OP residues in bat guano.

Given mounting evidence that bats in other locations are being exposed to OPs, the present work is a preliminary study to determine whether or not Indiana myotis as well as other species of bats are being exposed to OPs in Indiana.

METHODS

All bats submitted to the Indiana Department of Health Rabies laboratory since 1966 have been forwarded to one of the authors (JOW) at Indiana State University for identification and research purposes. Many of these bats exhibited behavior that brought them to the attention of humans, i.e., many were on the ground sick, dying or dead. From 1966 to 2003, about 200 to 400 bats were submitted annually, but only 5.4% of these proved rabid (Whitaker & Douglas in press).

Nine bats that had been submitted to the Indiana Department of Health, Rabies laboratory from 1998 to 2000 were submitted through the U.S. Fish and Wildlife Service to the Geochemical & Environmental Research Group, Texas A&M laboratory for chemical analysis in August 2001. Five Indiana myotis and four northern myotis, all non-rabid, were analyzed (whole body, minus the brain which had been removed for rabies testing). Analyses included: OPs, organochlorine insecticides, polychlorinated biphenyls (PCBs), and pyrethroids. Due to the large sample mass required for carbamate insecticide analysis (35 g) those contaminants could not be investigated. The bats were kept frozen prior to chemical analysis. No separate stomach content examinations were conducted on these bats.

Recent guano samples were collected from priority hibernacula by placing plastic sheets under roosting/hibernating Indiana myotis. These sheets were retrieved at various intervals, and guano pellets were transferred to chemically-clean glass jars and kept frozen until analysis. In addition, any fresh dead Indiana myotis found during biennial mid-win-

Table 1.—Organophosphate insecticides (μg/g wet weight) in the Indiana myotis (*Myotis sodalis*) and northern myotis (*Myotis septentrionalis*) found by members of the public and submitted to Indiana Department of Health for rabies testing. U, not determined.

	Myotis sodalis					*Myotis septentrionalis*			
ID #	16122	16204	16615	16638	16639	16729	16730	16784	16785
Date found	8/26 1998	10/21 1998	4/15 2000	8/22 2000	8/23 2000	8/29 2000	8/29 2000	10/6 2000	10/18 2000
County	Marion	Vanderburgh	Vanderburgh	Vanderburgh	Marion	Vanderburgh	Decatur	Davies	Vanderburgh
Body mass (g)	5.44	7.4	4.73	5.8	6.08	4.94	4.03	6.39	6.12
Sex	M	F	F	U	U	U	U	M	M
Lipids (%)	12.9	33.7	3.46	9.1	3.03	15	3.52	22.8	40.3
Moisture (%)	60.7	40.2	56.5	62.2	61.5	49.8	51.4	51.6	28.8
Dieldrin	0.06	0.13	0.09	0.09	0.08	0.10	0.04	0.16	0.23
Heptachlor epoxide	0.02	0.14	0.02	0.02	0.01	0.02	0.01	0.11	0.05
Oxychlordane	0.1	0.19	0.14	0.21	0.09	0.21	0.04	0.12	0.28
p′, p′-DDE	0.12	0.14	0.3	0.14	0.14	0.16	0.03	0.07	0.06
PCB total	0.62	0.53	1.3	0.92	—	4.2	0.89	0.39	0.8
Organophosphates:									
Chlorpyrifos	—	—	—	—	—	0.18	—	—	—
Diazinon	—	—	0.03	—	—	—	—	—	—
Methyl parathion	—	0.02	—	—	—	—	—	—	—

ter hibernacula surveys ($n = 6$) were collected for chemical analysis.

Gas chromatography (GC)/mass spectrophotometer (MS) method in single ion monitoring (SIM) mode was used to perform chemical analysis on the carcasses. The tissue samples were extracted by the National Oceanic and Atmospheric Administration (NOAA) Status and Trends Method (MacLeod et al. 1985) with minor revisions (Brooks et al. 1989; Wade et al. 1988). The tissue samples were homogenized with a Teckmar Tissumizer. A 1–10 g sample (wet weight) was extracted with the Teckmar Tissumizer by adding surrogate standards, Na_2SO_4, and methylene chloride in a centrifuge tube. The tissue extracts were purified by silica/alumina column chromatography to isolate the aliphatic and polycyclic aromatic hydrocarbon (PAH)/pesticide/PCB fractions. The PAH/pesticide/PCB fraction was further purified by high performance liquid chromatography (HPLC) in order to remove interfering lipids. The quantitative analyses were performed by capillary gas chromatography (CGC) with a flame ionization detector for aliphatic hydrocarbons, CGC with electron capture detector for pesticides and PCBs, and a mass spectrometer detector in the SIM mode for aromatic hydrocarbons (Wade et al. 1988).

RESULTS

Organophosphate insecticides were detected in three of the nine bats examined from the Indiana Department of Health, Rabies laboratory (Table 1). All the samples contained organochlorine pesticides. PCBs were detected in eight of nine bats (0.39–4.2 μg/g wet weight). No pyrethroid insecticides were detected (Table 1). Due to the small size of the sample, no statistical analysis could be performed.

Chlorpyrifos (OP) was also detected in every Indiana myotis carcass and guano sample from Ray's Cave and Wyandotte Cave, both important Indiana myotis hibernacula (Table 2). No other OPs were detected in the Indiana myotis carcasses that were found dead in the caves.

Dichlorvos was detected in Indiana myotis guano from three of the four caves at concentrations ranging from 11–86 ppb, wet weight (Table 2).

DISCUSSION

The three bats with detectable levels of OP insecticides in their carcasses were found in

Vanderburgh County. According to Indiana Agricultural Statistics Service census from February 1999, 55% of the total land area of Vanderburgh County is farmland (38% corn, 48% soybeans, and 12% wheat).

Chlorpyrifos is registered in Indiana for agricultural use on corn, soybeans and wheat to control agricultural pests. Up until 2002 it was also used in buildings to control cockroaches, fleas and termites. Today it has been phased out for home use (limiting the use for certified professional applicators) by EPA under a June 2000 agreement with the registrant (Dow AgroSciences which manufactures chlorpyrifos) (EPA 2000). Nevertheless, existing home use stocks purchased before 2002 may be used indefinitely for any purpose specified on the label.

Diazinon was registered in Indiana at 2000 for use on turf grass as well as for a variety of other homeowner uses, but residential uses have now been phased out.

In 1998, methyl parathion was registered for a variety of agricultural products such as corn, soybeans and wheat. Methyl parathion should only be used in open fields to control insects and is used as a spray (insecticides data courtesy of G.N. Saxton, Compliance Officer, Office of Indiana State Chemist, 2005 and ATSDR, Agency for Toxic Substances and Disease Registry).

Dichlorvos is registered for indoor, terrestrial non-food, greenhouse (food and non-food) and domestic outdoor use including turf and ornamental uses. There are no agricultural crop uses for this chemical. The majority of dichlorvos uses are indoors, including greenhouses, commercial, residential, industrial and farm buildings, food handling establishments and more (EPA 2005).

Several authors have suggested that since OPs do not accumulate in living tissue their presence is indicative of recent exposure prior to death (O'Shea & Clark 2002; Hill 1995, 1989). Nevertheless, the presence of OP residues in the absence of demonstrated ChE inhibition does not confirm clinical effects nor suggest causation in a specific mortality. It is important to state that in the present study the cause of death was not determined nor was it determined how long the OP-infected bats lived after they were exposed. It is also important that the samples were frozen for 10 months to three years prior to the chemical

Table 2.—Organophosphorous insecticide residues (ppb, wet weight) in Indiana myotis guano and carasses from several priority Indiana myotis hibernacula in Indiana. U, not determined. OPs not detected included: dimethoate, disulfoton, ethoprop, fensulfothion, EPN, fenthion, malathion, merphos, methyl parathion, azinphos-methyl, phorate, demeton, diazinon, trichloronate, coumaphos, tetraethylpyrophosphate, mevinphos, monocrotophos, naled, parathion, ronnel, sulfotepp, sulprofos, tetrachlorvinphos, and protothiofos.

	Guano from caves					Whole *Myotis sodalis*					
Cave	Coon	Grotto	Ray's	Ray's	Wyandotte	Ray's	Ray's	Wyandotte	Wyandotte	Wyandotte	Wyandotte
Date	April 04	April 04	April 04	Sept 03	April 04	Jan 03	April 04	Feb 02	Feb 03	Feb 03	Feb 03
Body mass (g)	N/A	N/A	N/A	N/A	N/A	7.9	8.0	6.2	4.6	5.1	5.9
Lipid (%)	0.4	0.1	0.3	0.7	1.1	U	U	U	U	U	U
Sex	N/A	N/A	N/A	N/A	N/A	F	U	F	M	M	M
Moisture (%)	51.8	69.7	67.2	76.2	13.5	U	U	U	U	U	U
Chloropyrifos	<0.1	<0.08	0.7	0.2	1.0	0.8	1.1	1.6	3.2	4.2	1.1
Dichlorvos	86	11	—	—	20	—	—	—	—	—	—

analysis. Given that OP residues are supposedly rapidly eliminated from the living body (Hill 1989) and do not persist in the environment for long, it is likely that the residue levels detected are lower than they were in the body at the time of exposure.

Freed et al. (1979) studied the degradation of OPs in water. They found that the half life of OPs in aqueous systems (pH = 7.4) at 20 °C ranged from seven hours to 130 days, according to the specific OP compound. OPs degradation rates at 37 °C were 5–7 times greater. Ferrando et al. (1992) obtained similar resaults. They tested persistence of various insecticides (organochlorines, OPs and carbamate) in tap water (pH = 7.5 ± 0.5) and unfiltered lake water (pH = 9.0 ± 0.5) kept at 22 °C. The most persistent insecticides in their study belonged to the OP (diazinon, half-life of 70.54 h in natural water and 79.19 h in tap water) and carbamate (thiobencarb, half-life 74.27 h in natural water and 247.66 h in tap water) groups. This implies that ChE inhibitors can build up in surface water after application to crop fields, especially since each field will be treated at a different time and sometimes more than once. They will persist in water for even longer during the colder spring months. The result can be an additional exposure media (water) to bats and other wildlife on top of the other exposure media (air, soil and food).

Even though ChE-inhibiting insecticides are labile in mammals; recovery of inhibited ChE activity from a single exposure may vary from a few hours for most carbamates to 1–3 weeks for OP compounds (Hill 1995). Repeated application of even short-lived chemicals may cause cumulative physiological effects without a corresponding accumulation of chemical residues (Hill 1995). Although it is possible that the bats were exposed to OPs by dermal or respiratory routes while flying in areas where an OP had been sprayed, it is most likely that these OP residues come from consuming contaminated insects or drinking contaminated water. If that is the case, bats are apt to be re-exposed when feeding on the same insects or drinking the same water night after night until contamination ceased.

Clark (1986) and Clark & Rattner (1987) conducted OPs acute toxicity laboratory studies using bats. The bats were dosed once with high (near lethal) doses of OP and were kept (if they survived) for only 24 h before being sacrificed and tested to determine brain ChE activity. The relevance of these studies to field conditions in which chronic exposure to low doses is more likely to occur is questionable. Clark (1986) dosed little brown myotis and big brown bats (*Eptesicus fuscus*) by stomach intubation with methyl parathion. He found that bats lost coordination within 1 h and were still not able to right themselves at 24 h after exposure. Although it appears that bats are about eight times less sensitive than mice in terms of acute lethality, the oral dose estimated to cause loss of coordination in 50% of big brown bats was one-third or less than the LD_{50} of this species. Similar results were obtained when Clark & Rattner (1987) dosed little brown myotis with acephate. These data imply that exposure to non-lethal doses could result in death in the field when bats that have become debilitated are exposed to high risk situations such as predators, harsh sun, inclement weather, or drowning (Clark 1986). Another question was whether the lack of lethality during the 24 h studies might be related to bats entering torpor when subjected to stress—in this particular case, the stress of the toxicity study (Gordon 1993). This could have delayed acute effects therefore making it appear that bats are not as "sensitive" to OPs as mice. However, elongated torpor might cause energetic deficiencies when torpid bats do not feed for relatively long periods.

Sub-lethal inhibition of brain ChE activity, after OP applications to agricultural fields, were documented on several occasions. Maul & Farris (2005) documented significant levels of cholinesterase (ChE) inhibition in 8.7% of northern cardinals (*Cardinalis cardinalis*) sampled from agricultural field edges in northeast Arkansas 3–21 days post treatment. Guillén et al. (1991) documented whole body residues of fenitrothion in *Pipistrellus pipistrellus* the day after (0.54 ppm) and 21 days after (0.84 ppm) rice fields were treated. In addition, mean brain ChE levels in bats collected 21 days after treatment were significantly reduced. If similar sub-lethal reductions are occurring in the ChE enzymes of Indiana bats as a result of these documented OP exposures, and if ChE reductions are cumulative, persisting for many days, both the risk of trauma due to navigational impairment increases and foraging ability might be impaired such that their high energy requirements could not be met. Even if the bats themselves manage to survive and recover, pregnant and nursing females, too low on energy, could lose their pups.

Sub-lethal doses of an organophosphate might reduce bats foraging capability for a few hours or days, and that could be sufficient to cause starvation-related mortality that would be nearly untraceable using current analytical chemistry techniques. Indeed, bats necropsied at the U.S. Geological Service Wildlife Health Laboratory in Madison, Wisconsin are often found to be emaciated (Grace McLaughlin, USGS Wildlife Health Laboratory pers. commun).

Eighteen different OPs were detected in guano from maternity roosts of cave bats (*Myotis velifer*) in Texas (Land 2001). The presence of OPs in guano from Texas and from caves in Indiana not only confirms bat exposure to OPs, it also demonstrates oral exposure (food, water or probably both). Demonstration of oral exposure through contaminated insects would be clear evidence that OPs are entering the food chain. If we assume low OP bioaccumulation in bats, their presence in guano may result from OP insecticides being applied near those hibernacula.

A specimen of Indiana myotis (16615), submitted in April 2000 contained detectible levels of diazinon (Table 1). It is likely that this exposure resulted from feeding on insects associated with a spring-time agricultural or turf grass application. Just emerging from hibernation therefore having low energetic reserves could have made that bat more sensitive to the toxic effect of OPs. A northern myotis (16729) submitted in August 2000 was found with detectable levels of chloropyrifos (Table 1). It appeared to be in good condition, based on 15% lipid concentration in its body. It is possible that this bat was exposed to chloropyrifos due to agricultural application or other use. An Indiana myotis (16204) submitted in October 1998 had detectible levels of methyl parathion and a whole body lipid concentration of 33.7% (Table 1). Speakman & Thomas (2003) indicate 30% fat reserves as the normal level prior to hibernation. It is more difficult to suggest a reason for using methyl parathion at the end of October. Although the cause of death was not determined in any of the nine bats sampled, it is possible that OP insecticide exposure was a contributing cause of death in these three bats, especially since all three were in normal to good nutritional condition considering the season.

Of the 8262 bats submitted to the Indiana department of health rabies laboratory during the years 1966–2003, only 5.4% (445 bats) were rabid (Whitaker & Douglas in press). This means that nearly 95% of the bats died from other causes. Considering that many of these bats were found under suspicious circumstances (i.e., often ending up on the ground around human habitations), and that OPs can adversely influence behavior, we suggest that OPs may have directly or indirectly led to the deaths of the three bats. The fact that three of nine bats were found to be exposed to OPs might suggest frequent exposure to those toxicants in the overall population. Because of this, and also because of the lack of information regarding sub-lethal effects of these ubiquitous neurotoxicants to living bats, more research is needed.

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HIBERNATION OF THE EASTERN PIPISTRELLE, *PERIMYOTIS SUBFLAVUS*, IN AN ABANDONED MINE IN VERMILLION COUNTY, INDIANA, WITH SOME INFORMATION ON *MYOTIS LUCIFUGUS*

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ABSTRACT. We studied the number of hibernating eastern pipistrelles, *Perimyotis subflavus,* in Copperhead "Cave," an abandoned mine in Vermillion County, Indiana, just across the river from Montezuma, Parke County. The number of bats increased through early December, remained high through April, then declined through May. A few bats remained at the same spots in the mine for up to 18 weeks or throughout the entire winter, but we also observed numerous short bouts of torpor. Pipistrelles usually hibernated singly (observed 3628 times), but were in pairs 108 times, triplets 10 times, and 4 bats were together on one occasion. Winter mass losses averaged 2.65 grams for males and 2.50 g for females. Pipistrelles generally hibernated in different chambers than did *Myotis lucifugus.* Few (5) pipistrelles emerged from the mine in winter (December through February) and few exited in spring (0.4 per night) until May. In fall, they were active through October, with the end of the major swarming in mid-October.

Keywords: Hibernation, Eastern Pipistrelle, *Perimyotis,* bats, mines

INTRODUCTION

Bats, like other mammalian hibernators, arouse periodically between torpor bouts during hibernation (Folk 1940; Krzanowski 1959; Daan 1973). During arousal, bats fly within and occasionally leave hibernacula (Guthrie 1933; Hooper & Hooper 1956; Mumford 1958; Tinkle & Patterson 1965; Daan 1973; Whitaker & Rissler 1992*a,b*).

Individual pipistrelles, *Perimyotis subflavus,*[2] usually hibernate in relatively small numbers in caves and mines, and they use more caves and mines for hibernation than do other species of bats in the eastern United States (Brack et al. 2003, 2004). Hibernacula are apparently usually within about 100 km of the summer roosting area, as the longest migration recorded for this species was 85.0 km (Griffin 1940). Brack and Mumford (1984) showed that pipistrelle distribution in Indiana was coincident with the southern edge of the Wisconsinan glaciation and the northern edge of the cave region, which suggests that the presence of suitable hibernacula may influence geographic range in this species.

Males and females hibernate in the same caves and mines, although most individuals are solitary during hibernation (Guthrie 1933; Hitchcock 1949; Hall 1962; McNab 1974). Mumford and Whitaker (1982) found eastern pipistrelles hibernating in contact with another bat in only one instance. Laval and Laval (1980) suggested that pipistrelles are the earliest bats to enter hibernacula in autumn, and the last to emerge in spring.

Brack and Twente (1985) marked bats with fluorescent paint and then recorded their individual locations three times per week between December and March for 2 years. They found that pipistrelles were more variable in the length of time spent at one location than big brown bats, *Eptesicus fuscus,* or little brown myotis, *Myotis lucifugus.* Brack and Twente (1985) recorded 20 instances of bats spending greater than 50 days in the same spot, three over 98 days, and one of 111 days in their sample of 155 individuals, although undetected movements could have occurred. Harden and Hassell (1970) and Daan (1973) likewise suggested that bats may arouse, move, and return to the same location. Twente et al. (1985) reported that individual pipistrelles hibernating at 5 °C stayed in one place for time periods of up to 27 days. They concluded that bats tended to employ longer torpor bouts at lower temperatures. Menaker (1964) noted that of six periods of hibernation at 3–5 °C, 26 individuals hibernated for less than 5 days, whereas two hibernated more than 80 days.

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[2] *Pipistrellus subflavus* has now been placed into its own genus, *Perimyotis* Menu, 1984 (Hoofer and Van Den Bussche 2003; Hoofer et al. 2006).

Mean ambient temperatures (T_a) to which pipistrelles are exposed during hibernation are influenced by latitude: 6.8 °C in Minnesota (Swanson & Evans 1936) to 14–18 °C in some caves in Florida (Rice 1957). Rabinowitz (1981) argued that both high and low temperatures were avoided. McNab (1974) argued that these bats choose the warmest temperatures, which are different depending on the geographic location of the hibernaculum. Pipistrelles have been consistently recorded hibernating at temperatures higher than those used by the little brown myotis. Hall (1962) and Henshaw & Folk (1966) observed that little brown myotis hibernate between 1–13 °C. They usually occupy deeper parts of caves or mines where temperatures are relatively stable (Hitchcock 1949; Hall 1962; Fitch 1966). Given their small size, it is not surprising that the hibernation strategy used by the eastern pipistrelle is to seek out areas with stable temperatures, where they can remain in prolonged torpor (Davis 1964; McNab 1974). Fitch (1966) found that male eastern pipistrelles had a steady decrease in mass of 39% between September and April, and that females had a decrease of 29% from September to March.

Most caves and mines in Indiana contain a few eastern pipistrelles in winter, but Copperhead "Cave," actually a long abandoned mine, has one of the largest hibernating populations in the state (Brack et al. 2003, 2004; Whitaker & Rissler 1992*a*). Whitaker and Rissler (1992*a*) found that Copperhead mine serves as a hibernaculum for approximately 200 eastern pipistrelles, 130 little brown myotis, and 900 northern myotis, *Myotis septentrionalis*. They assessed activity at the mouth of the mine for 15 months (including 2 winters) using weekly harp trapping and found little movement of pipistrelles in and out during winter. They captured only five individuals from 30 October to 17 April, 1989–1990, and two individuals from 19 October to 5 April, 1990–1991. Northern myotis and little brown myotis were much more active during these time periods, with 91 little brown myotis captured in 1989–1990 and 419 in 1990–1991, and 474 northern myotis in 1989–1990 and 210 in 1990–1991. The absence of pipistrelles at the mine entrance in winter suggested much less inter-cave, and possibly intra-cave, activity than by the little brown myotis during the hibernation period.

Because of Copperhead mine's large hibernating population of pipistrelles, it provides a useful opportunity to learn more about the behavior and activity of this species during hibernation and to address questions from the literature about hibernation in pipistrelles and bats in general.

Our objectives were to: 1. Quantify the timing of hibernation onset, the timing of increasing, population peak and decreasing population size, and the timing of the end of hibernation. 2. Determine the length of time pipistrelles remained in specific roost sites within Copperhead during hibernation. 3. Assess clustering during hibernation. 4. Quantify winter mass loss by comparing the mass of bats entering the mine in fall with those exiting in spring. 5. Compare T_a at pipistrelle hibernation sites within Copperhead with that of sites used by the little brown myotis.

METHODS

Copperhead "Cave" is actually an abandoned clay mine in a bluff, 1 km west of the Wabash River and 1.5 km northwest of Montezuma, Vermillion County, Indiana (St. Bernice Quadrangle N 39°48′08″ W 87°23′17″; elevation 235 m). Bats were studied from 7 October 1994 to 17 June 1995, and from 6 September 1995 to 3 May 1996. The "growing season" in this locality extends from early May to early October. There are no natural caves in the area. The mine is 120 km northwest of the unglaciated cave country of southern Indiana (Whitaker & Rissler 1992*a,b*). The entrance is 1.4 m high and 2.5 m wide, and opens into a series of chambers occupying approximately 400 m^2. The first six rooms, and passages connecting them, were used for the study (Fig. 1). The three back rooms were not studied because of safety concerns. Data collection stopped in spring when females left for maternity colonies. Data were taken approximately once per week the first year, and

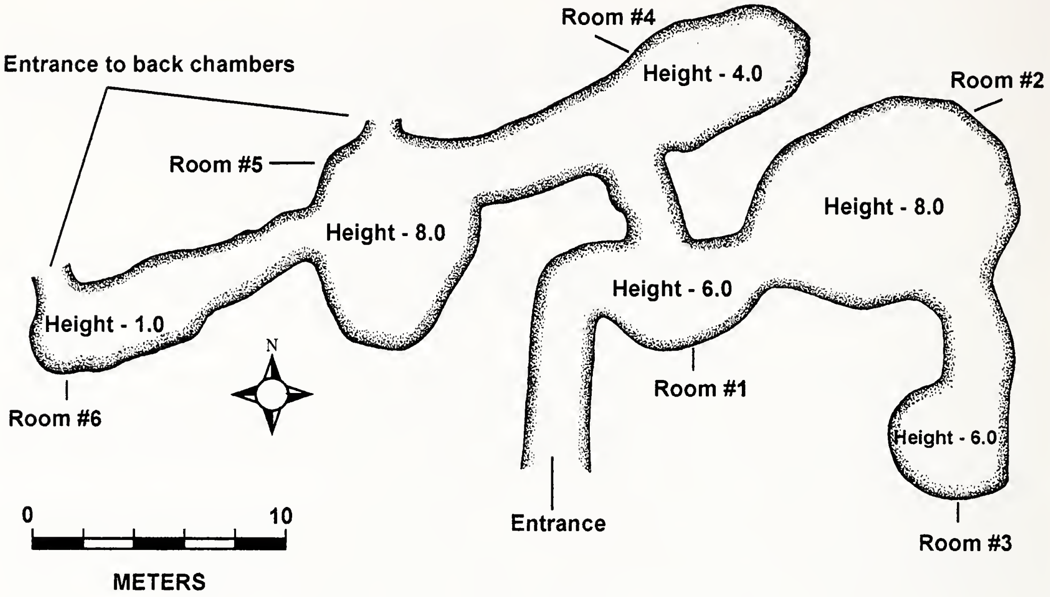

Figure 1.—Copperhead Cave, an abandoned mine in Vermillion County, Indiana. Heights at maximum points in meters.

every third week the second year. Less frequent visitations in the second year was an attempt to determine if frequent observation affected the arousals, as reported by Thomas (1995). On each visit we captured bats at the mine entrance in a double frame harp trap. The area around the edge of the trap was covered with bird netting to force bats through rather than around the trap. The trap was continuously tended dusk to midnight. We recorded species, gender, reproductive status, and mass of each bat captured. All bats were released unharmed.

To gather data on movements of pipistrelles inside the mine, we painted white numbers on the mine wall immediately below and as close to the hibernating bats as possible, and recorded these locations on maps. We observed each spot on every visit to determine if bats continued to use these locations. The T_a was recorded at the mine wall near the bats using a Taylor pocket thermometer. From 5 January 1995 through the end of the study, numbers were placed under some little brown myotis at the same time and in the same manner in order to compare the roost T_a selected by the two species. Our definition of group behavior or clustering was that bats had at least part of their body in contact with one or more bats.

We tested whether mean $T_{a,}$ T_a stability, and T_a range were correlated with numbers of bats in each chamber to determine which factors influenced bat numbers. Temperature stability for a given room was defined as the number of times the temperature fluctuated between visits within a room during the time period of the study. Total stability for each room was calculated by counting the number of times a temperature occurred in the room and multiplying it by designated rank (the lowest rank number, 1, was assigned to the temperature that occurred most often in that room). For example, in Room 1, 12 °C occurred seven times, therefore was multiplied by 1 (rank). These values were then added, to establish an overall stability value for each room. Room 3 had the lowest stability scores of 16 (calculated based on Kendall's ranking procedure) in the first year and 8 in the second year, and was therefore the most stable of all rooms during both years. Room 4 had ranks of 21 and 10, the second lowest. We used Kendall's coefficient of concordance (Zar 1984) to determine how average temperature, range, and stability were related to numbers of bats in each room. Rooms with the most stability were determined by removing variables systematically and testing for significance of remaining variables.

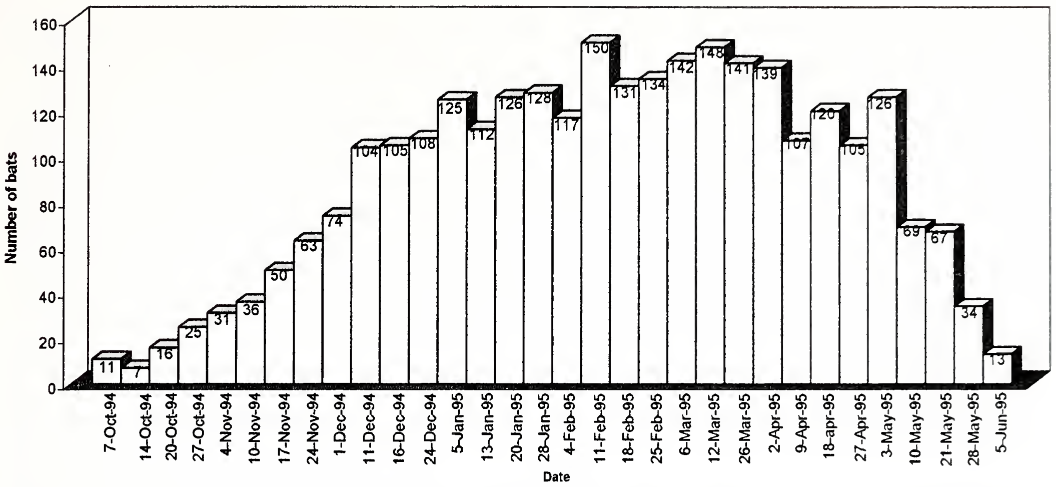

Figure 2.—Total number of *Pipistrellus subflavus* within Copperhead, an abandoned mine for 1995–1996, located in Vermillion County, Indiana.

RESULTS

We caught 119 eastern pipistrelles in the bat trap during the two years, and our capture rates were similar to those in a previous study at the same mine (Whitaker and Rissler 1992*a*). Eastern pipistrelles were common at the entrance in August, and significantly decreased in 1994–95 from September through December (χ^2 = 51.8, 3 df). Unlike little brown and northern myotis which flew in and out of the entrance throughout the winter, only five pipistrelles were caught from 1 December to 31 March during the 2 years of study. Few pipistrelles exited until May in either year, averaging 0.4 per night in April and 7.3 per night in May.

Hibernation onset.—Bats caught in the harp trap but especially numbers observed in the mine (Fig. 2) were used to determine the timing of hibernation onset and the gradual increase in numbers of hibernating bats. No trapping was done in August, but in September, numbers averaged 8.0 per night, falling to 6.6 in October. The major swarming period ended in mid-October.

Eleven eastern pipistrelles were found in the mine on 7 October in year 1, when data collection started (Fig. 2). Numbers then fluctuated throughout the winter but increased to 125 by 5 January and peaked at 150 on 11 February. They steadily declined until all had left the mine for the summer (Fig. 2).

The data for the second year were not presented, since observations were made every third week. However, they showed a similar pattern. In the second year, 3 bats were present on 6 September, and this number increased to 139 bats by 7 February. There were fewer fluctuations recorded than in year 1, but that was clearly due to less frequent visits.

Duration of time bats spent in one place.—Bats did not show strong long-term fidelity to specific roost spots within the mine. Often bats were in a roost site for only one observation. This occurred 1153 times. Many individuals were marked, 1103 were seen in the same position one week later, 277 were seen two weeks later, 254 were in place for 3–5 weeks, 54 for 6–9 weeks, 23 for 10–12 weeks, 13 for 13–17 weeks, and 7 for 18–25 weeks. The longest periods were 23 and 25 weeks (1 bat each). It is likely, of course, that sometimes a bat awoke then came back to the same position, or that one bat replaced another.

Decline in numbers of bats with approaching spring.—In year 1, there was an initial spring decline of 32 bats between 2 April and 9 April, followed by fluctuations from 18 April to 3 May, prior to the large decline (54.8%) between 3 May and 10 May (Fig. 2). In the second year, the largest decline was between 10 April and 1 May (N = 63 bats; 63%), indicating that most bats were leaving for summer roosts. No pipistrelles were caught in the trap on 10 April, suggesting that most bats left after this date, as compared with the next trap date, 9 May, when 4.25 pipistrelles per hour were caught. For both years combined, April averaged 0.4 bats per night and May 7.3 bats per night. Thus, pipistrelles exited the mine at the end of April through May.

Clustering during hibernation.—We found eastern pipistrelles in hibernation 3747 times. Most hung singly (N = 3628 ; 96.8%), but pairs were observed 108 times, 3 bats 10 times, and 4 bats once. In contrast, little brown myotis were found hibernating singly in Copperhead Mine on 957 occasions (43.9%), and in groups of up to 15 individuals.

Overwinter mass loss.—Male pipistrelles exhibited a significant average mass loss between fall (October) and spring (May), at about 2.65 grams (t = 3.14, df = 57, $P >$ 0.01). Females showed a similar loss of about 2.5 grams (t = 2.49, df = 34, $P >$ 0.02).

Roost temperature preference.—Pipistrelles were found more often in rooms 3, 4, and 5 during both years (Table 1). The number of eastern pipistrelles per room/per visit, in year 1, from highest to lowest was Room 4 ($\bar{x}$ = 32.4), Room 5 ($\bar{x}$ = 29.4), Room 3 ($\bar{x}$ = 19.0), Room 2 ($\bar{x}$ = 10.4), and Room 1 ($\bar{x}$ = 4.6). In temperature stability, again highest to lowest, they were Room 3 (stability value = 16), Room 4 (21), Room 1 (24), Room 5 (24), and Room 2 (33). There was a significant influence by temperature variables in the rooms (χ^2 = 14.82, df = 5, $P <$ 0.025) for year 1. Rooms with the most stable temperatures tended to harbor the greatest number of pipistrelles (Table 1). The variables of stability and range, combined, as compared to number of bats within rooms, were significant (χ^2 = 11.55, df = 5, $P <$ 0.05). Range of temperature had the second most influence in bat numbers within rooms.

Temperature variables did not influence sites used by little brown myotis, but percentages for both years show that little brown myotis more frequently hibernated in Room 2 (Table 1). Between January and May 1995, 73.5% of little brown myotis hibernated in Room 2. This value was 87.0% in 1996. Mating of eastern pipistrelles occurs mostly in fall and spring (Fugita & Kunz 1984). However, eastern pipistrelles were observed copulating on three occasions in the hibernacula: 18 and 28 February, and 16 March.

DISCUSSION

Numbers of pipistrelles increased in the mine in the fall, reached highest numbers from November through March, and then decreased (Fig. 2). This is logical as bats gather in the fall to swarm and breed; some stay for hibernation, and in spring, leave for summer roosts.

Present data are similar to those of Whitaker and Rissler (1992*a*), although the latter authors did not catch any eastern pipistrelles at the mine entrance past October in 1990, whereas during the present study 1.3 bats per night were caught in both November and December. No pipistrelles were caught by trapping in January, February, or March.

Whitaker and Rissler (1992*a*) found that eastern pipistrelles exited the mine between 27 April and 26 May 1990. They caught bats at a rate of 0.4 per night in March, 3.2 per night in April, and 6.1 per night in May, again similar to data from the present study.

The increases of pipistrelles in the mine in fall and early winter (November and December) did not correlate well with the number of bats caught in the trap. This disparity may arise from several sources. Bats may have been entering and exiting from the back rooms. (Earlier visits indicated pipistrelles did occupy these rooms.) A few pipistrelles may occasionally have been out of sight in cracks and crevices, but most hibernating pipistrelles were easily seen. However, the main reason was probably that many of the bats entering in late autumn/early winter remained in the mine, whereas earlier, many of the bats caught at the entrance probably included many more individuals moving through rather than hibernating in the mine.

Bats and other hibernating mammals arouse periodically during hibernation (Lyman et al. 1982). Thomas (1995) used infrared cameras to determine effects of disturbance on hibernating little brown myotis in a cave. Some individuals aroused and stayed active for 2.5–7.5 hours after he entered a cave containing about 1300 hibernating bats. He indicated that light, sound, and possibly a rise in temperature associated with presence of humans in the hibernacula provoked arousals in a portion of the population of hibernating bats. The addi-

Table 1.—Mean number (±SE) of bats and mean temperature (°C) per day by month (±SE) in Copperhead "Cave," Vermillion County, Indiana.

Month	Number of visits	Rooms	1	2	3	4	5	6	Totals
Oct.	5	mean temp	18	17	14	16	17	16	
		P. subflavus $\bar{x}$/day	3	1	2	5.2	5.6	0.6	15.6
		M. lucifugus $\bar{x}$/day	0	2.3 ± 0	0.2	0	0	0	3.4
Nov.	6	mean temp	15 ± 4	17 ± 1	14 ± 0	15 ± 1	15 ± 1	16 ± 0	
		P. subflavus $\bar{x}$/day	2.2 ± 1	4.3 ± 0	6.2 ± 0.5	17.5 ± 10	15.3 ± 5	2.7 ± 0.5	48.2
		M. lucifugus $\bar{x}$/day	0	6.8 ± 5.5	0.3	0.2	0	0.5 ± 1.5	7.8
Dec.	5	mean temp	11 ± 0	12 ± 0	12 ± 0	12 ± 0	12 ± 0	12 ± 0	
		P. subflavus $\bar{x}$/day	4.6 ± 0	12 ± 0	18.6	37.4 ± 0	25.8 ± 0	4.8 ± 0	103.4
		M. lucifugus $\bar{x}$/day	0	6.8 ± 0	0	0.2	0	0.6	7.6
Jan.	5	mean temp	13.8 ± 1.2	13.8 ± 0.6	12	13.5 ± 0.2	13.6 ± 0.3	13.3 ± 0.3	
		P. subflavus $\bar{x}$/day	6.2 ± 1.7	11.8 ± 1	24.4	41.4 ± 6.9	38.2 ± 4.2	9.2 ± 1.8	131.2
		M. lucifugus $\bar{x}$/day	4.4 ± 2.7	54.6 ± 5.7	2.6	12.2 ± 3.9	13.2 ± 3.2	0.2	87.2
Feb.	6	mean temp	11.5 ± 0.3	11.8 ± 0.3	11.6	12 ± 0.2	12.6 ± 0.2	13.3 ± 0.2	
		P. subflavus $\bar{x}$/day	7.8 ± 1.6	16.5 ± 0.8	24.3	44.5 ± 3.3	44.8 ± 3.3	9 ± 1	147
		M. lucifugus $\bar{x}$/day	12.3 ± 3	94.8 ± 2.6	1.2	1.5 ± 0.8	4.3 ± 1.3	0.2 ± 0.2	114.3
Mar.	5	mean temp	11 ± 0.3	12 ± 0.3	12 ± 0	11.8 ± 0.2	11.7 ± 0.4	11.5 ± 0.4	
		P. subflavus $\bar{x}$/day	4.8 ± 1.4	15.6 ± 1	28 ± 2.6	44 ± 2.2	44.4 ± 2.2	6.4 ± 1.4	143.2
		M. lucifugus $\bar{x}$/day	14.8 ± 3	111.2 ± 6	5.4 ± 1.5	1.4 ± 0.4	1.4 ± 1	0	134.4
Apr.	4	mean temp	12.3 ± 0.4	12 ± 0.6	12 ± 0	11.8 ± 0.3	12 ± 0.3	11.8 ± 0.3	
		P. subflavus $\bar{x}$/day	5 ± 1.1	10.5 ± 1.9	31 ± 0.4	42.3 ± 6	37.5 ± 2	5.5 ± 1.2	131.8
		M. lucifugus $\bar{x}$/day	11.5 ± 6.4	52.5 ± 35	4.3 ± 0.8	3 ± 1.2	4 ± 2.5	0	75.3
May	2	mean temp	12 ± 0	13 ± 0	12 ± 0	12 ± 0	11.5 ± 0	11.5 ± 0	
		P. subflavus $\bar{x}$/day	6 ± 2.5	12.5 ± 0.5	24.5 ± 14	23 ± 19	18.5 ± 13	2 ± 2	86.5
		M. lucifugus $\bar{x}$/day	0.5 ± 0.5	24 ± 4	0	0.5	0	0	25.0
Total numbers of bats per room during the 38 visits									
		P. subflavus							
		Total no.	176	394	721	1228	1118	201	
		No. per day	4.6	10.4	19.0	32.4	29.4	5.3	
		M. lucifugus							
		Total no.	217	1747	68	92	115	8	
		No. per day	5.7	46.0	1.8	2.4	3.0	0.2	

tive effect of arousals provoked by human disturbances may deplete fat stores and reduce chances for survival of individual bats. Thomas (1995) reported that arousals in his study were limited to a relatively small number of individuals. Because Thomas (1995) indicated that some bats were awakened by his presence in the hibernaculum, we reduced disturbance the second year to see if weight losses were different between the two years of study. Interestingly, mass loss was higher for both males and females in the first year. Less weight loss in the second year (although not significant) suggests that disturbance from research activity may have negatively affected the mass of the bats. Unpublished mass loss data were available from the 1990–1991 field season at Copperhead. The average mass loss for males was 2.73 grams, and the average for females was 2.53 grams. These are comparable to the average mass loss found in the present study. Johnson et al. (1998) found a relationship between human visitation and weight loss for the Indiana myotis (*Myotis sodalis*). In contrast to the eastern pipistrelle, the Indiana myotis hibernates in large clusters, and disturbance from aroused neighboring bats may contribute greatly to the disturbance from human visitation.

Whitaker and Rissler (1992*a,b*) reported that the influx of eastern pipistrelles began in August and swarming tapered off through September and October. Present data were similar to those of Whitaker and Rissler, with few pipistrelles caught in winter. However, more were captured in April.

Whitaker and Rissler (1992*a*) counted all bats in the mine, including the back rooms, on four occasions. They found 201 eastern pipistrelles on 23 February 1988, 113 on 14 January 1989, 92 on 27/29 December 1989 and 170 on 3 March 1991, or an average of about 144 eastern pipistrelles hibernating within the mine. These were similar to the maximum numbers counted during the present study.

We expected that most pipistrelles would stay relatively inactive, and that individuals would remain loyal to specific locations in the cave throughout hibernation. However, we observed a great deal of movement between locations throughout the winter, interspersed between relatively long periods in one spot. Harden and Hassell (1970) found that eastern pipistrelles might return to the same location after moving. During the present study, there was no way to determine if a particular bat had awakened, and returned to the same location, or if another bat had replaced it at that location.

Little brown myotis and Indiana myotis cluster during hibernation. Twente (1955) remarked that this clustering behavior probably aids thermoregulation. McNab (1974) suggested that clustering species will cope better with colder cave temperatures than nonclustering species because solitary animals have a greater surface to volume ratio and dissipate heat more quickly than clustered animals. Eastern pipistrelles are a small bat that does not cluster, apparently mitigating the impact of temperature on its small size by hibernating in thermally stable environments.

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ACTIVITY PATTERNS IN A CAPTIVE COLONY OF JAMAICAN FRUIT BATS, *ARTIBEUS JAMAICENSIS*

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ABSTRACT. We examined activity patterns of a captive colony of Jamaican fruit bats (*Artibeus jamaicensis*) using an Anabat II echolocation detection system and visual observations. Results showed that this colony, subjected to a light-reversal circadian cycle (darkness *ca.* 1000–2000 h daily), adjusted its activity patterns to maximize activity during dark hours. Major activities, including flying and feeding, were most frequent shortly after dark hours began, and roosting alternately increased throughout the dark time blocks. Additionally, captive bat behavior appeared to follow expected patterns of natural populations; they fed away from the source of food and preferred to roost in smaller groups rather than in large ones. We, therefore, provide quantitative evidence that captive colonies may be useful in elucidating the behaviors of natural populations.

Keywords: *Artibeus jamaicensis*, behavior, circadian activity, echolocation

Jamaican fruit bats (Phyllostomidae: *Artibeus jamaicensis*) are leaf-nosed bats whose native range includes Brazil, the Bahamas, Antilles, Trinidad, Tobago, Key West, and from central Mexico south to Bolivia. This species tends to roost in caves, rock overhangs, rock fissures, buildings, hollow trees, and self-made leaf tents (Gorog 1999). Primarily frugivorous with a specialty in figs (*Ficus* spp.), Jamaican fruit bats also feed on mangos (*Mangifera* spp.), avocados (*Persea americana*), bananas (*Musa* spp.), and espave nuts (*Anacardium excelsum*; Morrison 1978; Ortega & Castro-Arellano 2001). This species often transports fruit to night roosts for feeding, acting as influential dispersers of tropical fruits (Gorog 1999). Often referred to as "whispering bats," Jamaican fruit bats emit three low-intensity FM pulses used primarily for obstacle avoidance while flying or perching (Heffner et al. 2003). A series of 40–60 kHz pulses usually precedes a 60–110 kHz harmonic, followed by pulses at 30–33 kHz (Novick 1963).

Fenton & Kunz (1977) found that wild populations of Jamaican fruit bats were most active during the first hours after dusk, which equates to *ca.* 2000–2200 h during summer months. Additionally, they found that activity peaked around midnight (*ca.* 2–4 h after dusk) and activity was less predictable and more sporadic in remaining dark hours (Fenton & Kunz 1977). Whether this species follows a similar pattern of activity in captivity is unknown.

The roosting behavior of wild colonies has focused on caves, in which a harem-like social hierarchy exists. Typically, one dominant male roosts with 2–14 females (Kunz et al. 1983; Ortega & Arita 1999), but larger groups of up to 20 individuals may form if subdominant males are present. Outside of harems, fruit bats may roost individually or in small clusters (Ortega & Arita 1999). Given the typically skewed sex ratio in captive fruit bat colonies, as well as limitation for space, it is unknown whether these group sizes will be as large or as socially structured in captivity as in the wild.

Altered fruit bat activity with respect to changes in light pattern is a generally accepted conjecture (Erkert 1978). However, the extent of change in behavioral activity has rarely been quantified (e.g., Erkert & Kracht 1978; Marimuthu 1984). To quantify how a captive colony of Jamaican fruit bats has acclimated to a complete light-reversal, we utilized an Anabat II detection system (Titley Electronics, Australia) to record echolocation calls in 24 h cycles. We supplemented this work with visual observations throughout their most active hours to document specific behavioral patterns. From these two methods of study, we hypothesized: 1) captive Jamaican fruit bats would alter their activity patterns (as documented by echolocation calls) in response to reverse light conditions. Specifically, they would mimic wild bat populations by markedly increasing activity immediately after lights were shut off and peak activity *ca.* 2–4 h after darkness had begun; 2) captive bat active behavioral patterns would reflect these echolocation patterns; bats would fly, feed, vocalize, and crawl more often immediately after lights were dimmed, and these bats would roost more often in later hours; 3) captive Jamaican fruit bats would roost and feed in ways similar to their wild counterparts, roosting in smaller groups and feeding away from the original food source. Given the limited space and minority of males in our captive colony, we expected a tendency toward small groups or solitary individuals. However, because we could not readily distinguish males from females in the enclosure, we could not speculate on the possibilities of social hierarchies in this captive environment.

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METHODS

Enclosure.—We studied a captive-born and -bred colony of 167 (32♂, 135♀) Jamaican fruit bats at the Potawatomi Zoo, South Bend, Indiana. Also in the exhibit were 19 Egyptian fruit bats (Pteropodidae: *Rousettus aegyptiacus*), which is one of the few megachiropteran bat species that echolocates (peak frequency = 20–40 kHz [von Herbert 1985 as referenced in Holland et al. 2004]). The 5.3 m long × 3.3 m wide × 2.7 m high enclosure contained two large horizontal plastic perches, four smaller plastic branches, as well as a large vertical perch that spanned the height of the enclosure. The glass display window also provided perching opportunities along a rim which butted up against the ceiling, as did air vents in the ceiling.

The zookeepers of the exhibit practiced reverse-daylight conditions to maximize bat activity during hours of public viewing. The enclosure was illuminated with fluorescent ceiling lights from *ca.* 2000–1000 h every day. Due to the interior location of the exhibit within the zoo building, the bats were not exposed to any natural daylight. Bats were fed chopped fruit twice daily (*ca.* 1030 h and 1330 h) placed in three hanging bowls while whole bananas were hung from smaller branches. Whole apples (*Malus* spp.) and oranges (*Citrus sinensis*) were also occasionally provided on smaller branches.

Echolocation patterns.—Bat activity was monitored in ten 24 h sampling periods (September 2005–April 2006) using an Anabat II detector and ZCAIM unit (Titley Electronics, Australia). This unit was set up in a corner of the enclosure, with the microphone/detector pointed at a *ca.* 45° angle toward the middle of the enclosure to maximize call recording ability and quality. If the Anabat system detected a call, it saved the call(s) in a file that encompassed 15 sec of elapsed time. In Analook 4.9g (Corben 2003), we documented the time at which these data files contained quality calls (>3 individual call pulses; Johnson et al. 2002). Because of the presence of Egyptian bats in the enclosure, only calls with average frequencies ≥40 kHz were counted as Jamaican fruit bat calls (von Herbert 1985 as referenced in Holland et al. 2004). The number of files with documented fruit bat calls was summed across 15 min periods, and the average number (with standard error) of files per 15 min was graphed to observe patterns across the 24 h sampling periods.

Behavioral observations.—Individual behaviors for colony members were observed in three-hour observational periods, all of which fell between 1000–1700 h when it was dark (and during hours in which zoo staff allowed access). Every 15 min, we documented the number of individuals performing any of five actions: flying, feeding, vocalizing (at frequencies < 20 kHz), crawling on the floor, and roosting. These four observations per hour were transformed into relative activity proportions, then averaged across seven 1 h time blocks (1000–1700 h). However, we restricted statistical analyses to six blocks between 1000–1600 h (n = 1 set of behavioral observations between 1600–1700 h).

Additional analyses examined bat preferences in feeding (at food cups *vs.* away from food cups; paired t-test) and roosting (in clusters of >7 fruit bats, 5–7 fruit bats, or 2–4 fruit bats; one-way ANOVA) behaviors. All statistical analyses were performed in SYS-

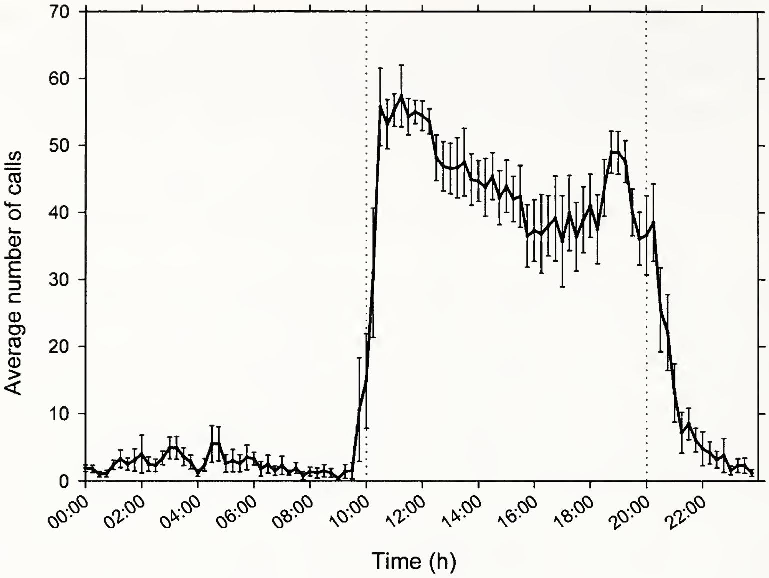

Figure 1.—Anabat echolocation calls for captive Jamaican fruit bat colony, exposed to reverse daylight conditions. Plotted is average number of calls per 15-min interval (with 95% CI) for ten 24-h observation periods from September 2005–January 2006. Time interval between dotted vertical lines indicates approximate hours in which bat enclosure was dark.

TAT 11.0 (Systat, Inc., Point Richmond, California).

RESULTS

We documented 18,509 Jamaican fruit bat echolocation calls during our study, and averaged them across 15-min intervals (Fig. 1). Bat activity was significantly higher in the enclosure during dark hours (1000–2000 h; $\bar{x} = 43.2 \pm 15.3$) than during light hours ($\bar{x} = 5.1 \pm 10.5$; $t = 41.4$, df = 579, $P < 0.001$). Furthermore, we found that the number of calls per hour differed across the seven time blocks in which bat behavior was recorded (Kruskal-Wallis test, K-W = 13.507, df = 6, $P = 0.036$; Fig. 1).

From 1000–1600 h, we found that bat flying ($F = 4.031$, df = 5, $P = 0.002$), feeding ($F = 4.965$, df = 5, $P < 0.001$), and roosting ($F = 5.597$, df = 5, $P < 0.001$) proportionally differed across time blocks (Fig. 2). Specifically, a Tukey's *post-hoc* test determined that more bats were flying in the 1100 h (i.e., between 1100–1200 h) than the 1200 h ($P = 0.021$), 1300 h ($P = 0.005$) and 1400 h ($P = 0.017$) time blocks. Bats fed less often during the 1300 h than at 1100 h ($P = 0.052$) and 1200 h ($P < 0.001$) and showed a trend in feeding less often at 1400 h than at 1300 h ($P = 0.117$), as well. A similar decline in feeding was observed from the 1300 h to the 1400 h ($P = 0.121$). Additionally, a paired *t*-test found that more bats were observed to feed away from food cups ($\bar{x} = 9.0$ individuals per observation) than at cups ($\bar{x} = 4.0$; $t = 6.667$, df = 107, $P < 0.001$) across all time intervals.

Finally, bat roosting peaked during the 1400-h time block, which was significantly more than roosting activity during the 1100 h ($P = 0.001$) and 1200 h ($P = 0.001$) time blocks. An ANOVA was used to examine group size in roosting, and found that the three size groups (2–4 individuals, 4–7 individuals, >7 individuals) differed significantly from one another ($F = 536.5$, df = 2, $P < 0.001$). The smallest grouping occurred more often than the medium (4–7) and large (>7) groups ($P < 0.001$ for both Tukey *post-hoc* comparisons), and individuals in medium groups occurred more often than those in large groups ($P = 0.006$). Crawling ($F = 1.694$, df = 5, $P = 0.143$) and vocalizing ($F = 0.958$, df = 5, $P = 0.447$) did not differ significantly across any time intervals.

DISCUSSION

As expected, the captive colony of Jamaican fruit bats exhibited a reverse-patterned

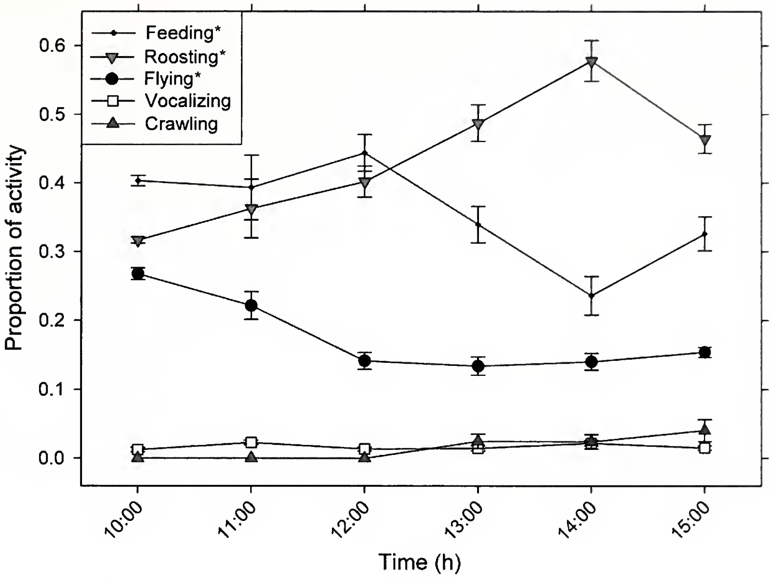

Figure 2.—Proportional bat activity (with 95% CI) for captive Jamaican fruit bat colony, exposed to reverse daylight conditions. Behavioral observations recorded from 1000–1100 h, e.g., are listed as an average at 1000 h. Bats were in darkness during all behavioral observation periods. An asterisk indicates that activity differed significantly across time blocks (see text for details).

circadian cycle complementary to the reverse-daylight pattern utilized in the Jamaican fruit bat exhibit. The Jamaican fruit bats showed significantly more echolocation activity during unlit hours. Their natural nocturnal rhythms, consistent with the hypothesis that the captive colony would adjust their circadian rhythms to the reverse-daylight cycles of the exhibit.

The Jamaican fruit bats exhibited corresponding behavioral changes with respect to the changes in light. Analyses of behavioral data showed there was statistically more feeding and flight activity during the earlier dark hours while roosting increased as the dark hours progressed. However, vocalizing and crawling were not prevalent activities and did not differ significantly across time. The behavioral data also revealed these captive fruit bats to have a tendency to feed away from the feeding cups, supporting the hypothesis that this group would retain wild tendencies. Despite being in a relatively small enclosure, the Jamaican fruit bats still carried their food away from the food source for feeding, continuing their natural role as seed dispersers (Fleming & Heithaus 1981).

However, the roosting groups were generally smaller than what had been found in previous studies of wild populations (Morrison 1978; Gorog 1999). While previous research (e.g., Ortega & Arita 1999) has shown that Jamaican fruit bats tend to form large harem groups for roosting in caves, these bats may display more opportunistic day-roosting behavior, depending on the natural surroundings and availability of resources (Morrison 1979). With few males present, a guaranteed food supply nearby, and multiple perching and roosting sites within the enclosure, several large roosts seem unlikely.

Peaks in flight and foraging activity of the captive colony of Jamaican fruit bats were also consistent with previous studies of wild Jamaican fruit bats. The captive colony presented two peaks of activity during the dark hours: one major peak during the first hour of darkness (0930–1000 h) and a minor peak *ca.* 1900 h (Fig. 1). Jamaican fruit bats in their natural habitats are more active during the first few hours of darkness with a maximum peak generally around midnight (Fenton & Kunz 1977). This peak at midnight might correspond to a peak activity in this captive colony at *ca.* 0930–1130 h.

Because zoo hours did not allow for 24-h behavioral observations of the captive colony, these data do not represent a full behavioral depiction of a typical captive Jamaican fruit bat. However, we emphasize that they may be useful in determining patterns during hours in which bats are most active. Future experiments might expand to 24-h behavioral observations for a more complete understanding of captive Jamaican fruit bat time budgets. Other experiments may include tagging and monitoring specific bats to better elucidate behavioral trends, and visibly marking the males to determine if a social structure exists within the colony.

These data suggest that captive colonies of Jamaican fruit bats will maintain their natural habits despite unnatural surroundings (i.e., a zoo enclosure and reverse-lighting). Additionally, because all of these Jamaican fruit bats were born in captivity, our data suggest that they have retained innate behaviors even under these unnatural conditions. We, therefore, suggest that captive Jamaican fruit bat behavioral studies may emulate behaviors of natural bat populations. For wildlife biologists and zoologists, further behavioral studies of captive populations, like those suggested, may assist in making management decisions for wild populations of Jamaican fruit bats.

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PROSPECTS FOR RESTORING RIVER OTTERS IN INDIANA

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ABSTRACT. Native populations of the North American river otter (*Lontra canadensis*) in Indiana declined sharply through the early 1900s due to unregulated harvest and habitat loss and were believed extirpated from the state by 1942. To restore otters to portions of their historic range, 303 otters (184♂:119♀) obtained from Louisiana were released at 12 sites in six watersheds (Muscatatuck, Patoka, south-central Ohio, St. Joseph, Tippecanoe, upper Wabash) between 1995 and 1999. Fifty-nine (43♂:16♀) of these otters (19.5%) were known to have died through December 2005, most (81%) in traps set for other furbearers and from collisions with vehicles. Otter sign was found on 31 of 43 surveys (72%) at each of 11 release sites sampled 0–6 years ($\bar{x}$ = 2.5) post-release. Overall detection rate was 20.6%. A total of 1328 post-release records, comprised of sightings (n = 884), accidental captures (n = 17), reports of otter sign (n = 170), and mortalities (n = 257) was compiled from 1995 through 2005. During this period, river otters were reported from 65 of 92 counties and 14 of 15 watersheds in Indiana. They are widely distributed in northeast, northcentral, and southern Indiana but are most common in 26 contiguous counties surrounding the 12 release sites. Otters are rare or were not reported from 57 counties in central Indiana. Reproduction was confirmed, either by recovery of untagged individuals and/or observations of family groups, each year after the initial release year and at 11 of 12 release sites. Size of family groups averaged 4.2 otters (range = 3–8). Ovulation rates based on presence of corpora lutea were 88% and 50% for adults and yearlings, respectively; mean litter size was 3.25 (*SD* = 1.12). Source of mortality for 206 (111♂:95♀) untagged otters killed in Indiana was incidental trapping (n = 131), collisions with vehicles (n = 68), drowning (n = 5), and unknown factors (n = 2); distribution by age class was 54 juveniles (27.3%), 64 yearlings (32.3%), and 80 adults (40.4%). Recommendations for otter management in Indiana include defining occupied range, collecting age-specific reproductive parameters, and developing management strategies to protect, maintain, and regulate restored populations.

Keywords: Distribution, furbearer, Indiana, *Lontra canadensis*, population, reintroduction, river otter, survey

The historical distribution of the North American river otter (*Lontra canadensis*) was widespread and encompassed most major watersheds in the continental United States and Canada (Hall 1981). Indigenous populations, however, declined sharply through the early 1900s, primarily due to unregulated trapping, water pollution, and habitat losses associated with human encroachment (Melquist & Dronkert 1987; Polechla 1990; Melquist et al. 2003). Such declines were especially severe in the central plains and midwestern regions of the United States (Hamilton & Fox 1987) where aquatic habitats were sparse and extensive agricultural activity had eliminated or degraded many wetland communities and riparian systems. In Indiana, native populations were also greatly reduced by the turn of the century (Lyon 1936). River otters were first protected in Indiana in 1921. Prospects for recovery, however, were unlikely; and they were believed to have been extirpated from the state by 1942 (Mumford 1969). Rangewide, otters were reported absent from five states, including Indiana, and protected in 17 others in 1976 (Deems & Pursley 1978).

During the 1970s, advances in furbearer management and broad environmental initiatives to improve water quality and protect or restore wetland and riparian habitats improved conditions for river otters in North America (Endangered Species Scientific Authority

1978). As a result, several state agencies began reintroduction projects to restore or enhance diminished otter populations in portions of their historic range. These initial efforts proved an effective strategy for recovery, and by 1998, over 4000 otters had been released in 21 states (Raesly 2001). Several states reported initial successes shortly after releases (e.g., Serfass & Rymon 1985; Erickson & McCullough 1987; Erickson & Hamilton 1988; Bluett et al. 1999; Johnson & Berkley 1999). Most reintroductions were ultimately considered successful (Raesly 2001); and by 2004, several states (e.g., Missouri, Kentucky, Ohio) had initiated or proposed regulated harvests of restored otter populations.

Although most reintroduction projects began more than 15 years ago, there are few published accounts that assess their long-term status and efficacy in restoring viable otter populations. In Pennsylvania, Serfass et al. (1993) documented a self-sustaining otter population 6–8 years post-release, which subsequently contributed to a statewide range expansion (Serfass et al. 1999). Hamilton et al. (2000) described unanticipated otter-human conflicts and management challenges following a highly successful program in Missouri. Bluett et al. (2004) reported a statewide distribution of otters and recommended de-listing following releases in Illinois. Herein, we provide a comprehensive evaluation of otter restoration efforts in Indiana from its origin in 1995 through 2005. We document population stability and growth, range expansion, and reproductive success during this 11-year period and discuss the species' legal status and impending issues concerning management of river otters in Indiana.

METHODS

Otter releases.—Johnson & Madej (1994) delineated 15 watersheds in Indiana, and based on habitat quality, identified the Muscatatuck, Patoka, southcentral Ohio, St. Joseph, Tippecanoe, and upper Wabash as most suitable for otter restoration. These six watersheds were located in northeast, northcentral, and southern Indiana (Fig. 1).

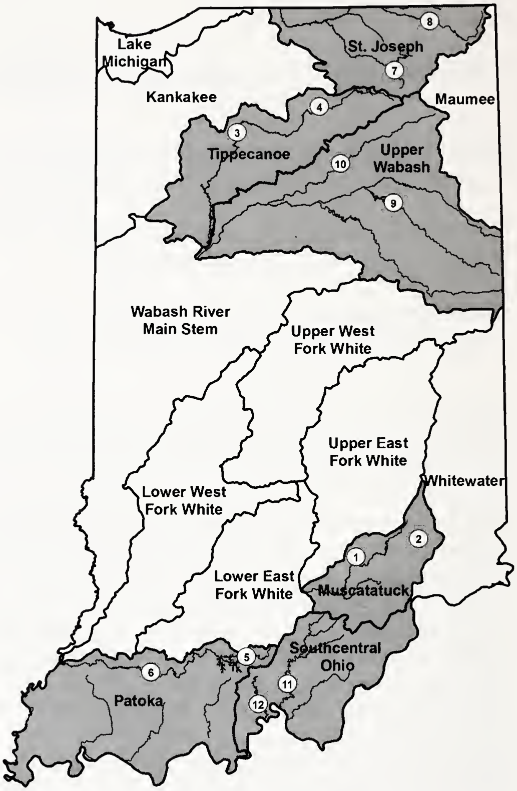

Figure 1.—Watersheds delineated for river otter restoration in Indiana. Shaded watersheds (n = 6) were identified by Johnson & Madej (1994) as highest priority for restoration. Numbered circles (○) represent location of release sites (n = 12) listed in Table 1.

Wild-trapped otters were purchased from a private supplier in coastal Louisiana (L.R. Sevin, Bayou Otter Farm, Theriot, Louisiana) because they are of the same subspecies native to Indiana (*Lontra canadensis laxitina*) and were used successfully in other midwestern states (e.g., Illinois, Iowa, Ohio, Missouri; Raesly 2001). Otters were captured in Louisiana during open trapping seasons using modified foothold traps and restraint techniques to reduce injury (Shirley et al. 1983). They were held in captivity for up to ten weeks before being transported to Indiana in agency vehicles, typically in late January. Upon arrival, otters were examined at the School of Veterinary Medicine, Purdue University and treated for trap-related dental or foot injuries (e.g., broken canines, lacerations, fractured digits). Each otter was administered ivermectin for internal parasites and multivalent vaccine products (e.g., Eclipse® 4, Fel-O-Vax® PCT, Vanguard® 5 CV-L) containing antigens for canine and feline diseases (i.e., distemper, rhinotracheitis, panleukopenia). A

Table 1.—Summary of river otter releases in Indiana, 1995–1999. Number in brackets denotes location of release site in Figure 1. Big Oaks National Wildlife Refuge was Jefferson Proving Ground at time of releases.

Watershed/release site	County	Release period(s)	No. otters released	Sex (M:F)
Muscatatuck River watershed				
[1]—Muscatatuck National Wildlife Refuge	Jackson	Jan 1995	25	15:10
[2]—Big Oaks National Wildlife Refuge	Ripley	Jan 1996; Jan 1999	31	19:12
Tippecanoe River watershed				
[3]—Tippecanoe River State Park	Pulaski	Jan, Feb 1996	26	16:10
[4]—Etna Green (Tippecanoe River)	Kosciusko	Jan 1996	24	14:10
Patoka River watershed				
[5]—Patoka Lake	Orange	Jan 1997	24	14:10
[6]—Sugar Ridge Fish & Wildlife Area (Patoka River)	Pike	Jan 1997	25	16:9
St. Joseph River watershed				
[7]—Mallard Roost WCA (South Branch Elkhart River)	Noble	Jan, Feb 1997; Jan 1998	27	17:10
[8]—Pigeon River Fish & Wildlife Area (Pigeon River)	Lagrange	Jan 1998	25	15:10
Upper Wabash River watershed				
[9]—Salamonie Lake	Huntington	Jan 1998	25	15:10
[10]—Eel River	Wabash	Jan 1998	25	15:10
Southcentral Ohio River watershed				
[11]—Blue River	Crawford	Feb 1999	23	14:9
[12]—Little Blue River	Crawford	Feb 1999	23	14:9

numbered Monel® fingerling and No. 3 tag was placed in each ear and interdigital membrane of the hind foot, respectively. Unless held for observation or rehabilitation, otters were released 3–4 days after their arrival in Indiana.

We released otters at two sites within each of the six watersheds (Fig. 1). Overall, 303 otters (184♂:119♀) were released during five consecutive winters between January 1995 and February 1999 at 12 sites in 11 counties. An average of 25.3 otters (range = 23–31) was released per site at a mean sex ratio of 1.55 males per female (Table 1). Otters exhibit delayed implantation that can postpone parturition for *ca.* 12 months after copulation (Liers 1951; Hamilton & Eadie 1964). Therefore, otters were released in late January, before peak breeding season, to improve the prospect that females would mate and bear young in their second spring after release.

Post-release field surveys.—Field surveys for otter sign (i.e., tracks, slides, scats, latrines, prey remains) were conducted during six winters between February 1996 and January 2001. Survey routes were limited to release sites and surrounding drainages within the six targeted watersheds. On each survey, accessible points along waterways (e.g., bridges, boat ramps) were visited to record the presence of otter activity. No limits were set on the length of stream bank examined, number of points visited, their distribution in the survey area, or proximity to one another. Number of nights elapsed since the last measurable snowfall, percent ice cover, snow depth, and type of otter sign (if present) were recorded at each survey point.

Post-release records of otters.—A variety of approaches was used to increase public awareness of Indiana's river otter restoration program and encourage post-release reporting of otter activity. Most releases received substantial media coverage by local, regional, and statewide newspapers and television stations and were well attended by the public. To solicit reports, "River Otter Release Area" signs were posted at release sites, boat ramps, and bait shops, and notices encouraging the reporting of otter sightings were published in annual hunting and trapping regulation booklets. Periodic news releases and articles in

Table 2.—Sources of mortality for river otters released in Indiana, 1995–1999. Distance expressed as linear distance to release site.

			Both sexes					
	n		Distance (km)			Days since release		
Source	Males	Females	Mean	SD	Range	Mean	SD	Range
Trapping	20	9	50.0	61.5	1.7–239.0	888	548	41–2149
Road-kills	13	5	29.3	36.5	3.1–152.3	478	761	4–2234
Unknown	3	2	18.2	27.1	2.1–65.6	130	146	44–298
Drowning	2	0	191.0	253.6	11.7–370.4	972	774	425–1519
Stress/exposure	2	0	8.2	2.6	6.3–10.0	6	1	5–6
Research-related	1	0	3.1	—	—	5	—	—
Shooting	1	0	2.5	—	—	2	—	—
All sources	42	16	42.0	67.6	1.7–370.4	630	661	2–2234

popular magazines generated other reports. Date, location, number of otters, and type of observation (e.g., sighting, road-kill, tracks, slides) were recorded for each report. Observers lacking experience with otters were contacted directly to evaluate the validity of their account. Licensed trappers, anglers, and personnel from federal and state natural resource agencies also provided reliable reports of otter activity.

Carcass examinations.—We attempted to recover the carcasses of all otters reported killed in Indiana between 1995 and 2005. Date, location, cause of death, sex, and physical condition were noted for each mortality. A lower canine was extracted and sent to a private facility (Matson's Laboratory, LLC; Milltown, Montana) for age determination using cementum annuli analysis. A parturition date of 1 April was used to assign otters into three age classes: juveniles (< 12 months of age), yearlings (1–2 years), and adults (> 2 years). We examined each carcass for ear and/or web tags and also searched for intraperitoneal transmitters used to monitor 15 otters in our first release (Johnson & Berkley 1999). Reproductive characteristics of females were assessed by examining ovaries and uterine horns for presence and number of corpora lutea, blastocysts, and embryos using methods described by Hamilton & Eadie (1964) and Gilbert (1987).

RESULTS

Fate of founder otters.—Fifty-nine (43♂:16♀) of the 303 otters (19.5%) released in Indiana were known to have died between January 1995 and December 2005. Otters killed in traps legally set for other furbearers (*n* = 29), primarily beaver (*Castor canadensis*), and collisions with vehicles (*n* = 19) accounted for 81.4% of the known mortalities (Table 2). Two males released at Big Oaks National Wildlife Refuge (NWR) were found dead within one week during an extended period of exceptionally severe winter weather. Both were recovered near frozen intermittent drainages within 10 km from the release site and were deplete of fat reserves; cause of death was presumed to be release-related stress and associated exposure. Two males drowned in commercial fishing nets, one was shot, and another died from an abdominal infection eight days after surgery to implant an intraperitoneal transmitter. Cause of death for five otters recovered post-mortem was unknown because of inconclusive evidence or advanced autolysis.

Time and point of release for eight otters (3♂:5♀) were unknown because they had lost their identification tags. They were killed 1.7–73.8 km ($\bar{x}$ = 19.4) from the nearest release site and had distinctive split ear pinnea and punctured or torn interdigital membranes where tags had been affixed. The remaining 51 otters traveled an average of 42.0 km (*SD* = 67.6), but most (53%) were killed within 15 km from their release site. Eight otters (7♂:1♀) were recovered in Kentucky (*n* = 5), Illinois (*n* = 2), and Michigan (*n* = 1), but the greatest distance traveled was 370 km for a male from Salamonie Lake that drowned 14 months post-release in a commercial fishing net in the lower Wabash River. Seventeen (35%) deaths occurred within two months af-

Table 3.—Summary of post-release field surveys for river otter activity near 11 release sites in Indiana, February 1996–January 2001. Overall detection rate is expressed as percent of points on all surveys conducted at a release site at which otter sign was confirmed.

				Surveys with otter sign		All surveys
Release site	No. surveys	Mean years (range) elapsed since release	Mean ± *SD* points per survey	*n*	Mean percent (range) of points with otter sign	Overall detection rate
Muscatatuck NWR	7	5.0 (4–6)	11.7 ± 10.5	4	25.0 (12.5–45.7)	25.6
Big Oaks NWR	9	2.8 (0–5)	15.1 ± 7.8	5	18.4 (7.7–37.5)	10.3
Tippecanoe River SP	2	0	16.5 ± 2.1	2	32.2 (11.1–53.3)	30.3
Etna Green	3	1.7 (0–5)	22.7 ± 19.3	3	29.8 (27.3–33.3)	29.4
Patoka Lake	2	2.0 (1–3)	27.0 ± 4.2	2	20.8 (16.7–25.0)	20.4
Sugar Ridge FWA	9	2.4 (1–4)	11.2 ± 3.6	5	27.7 (6.3–57.1)	17.8
Mallard Roost WCA	4	0.8 (0–2)	10.3 ± 1.3	3	36.7 (16.7–60.0)	26.8
Salamonie Lake	2	2.5 (2–3)	17.5 ± 0.7	2	20.3 (11.1–29.4)	20.0
Eel River	1	2.0	46.0	1	15.2	15.2
Blue River	2	1.5 (1–2)	15.0 ± 7.1	2	25.0 (20.0–30.0)	23.3
Little Blue River	2	1.5 (1–2)	16.5 ± 3.5	2	31.0 (26.3–35.7)	30.3
All sites	43	2.5 (0–6)	15.3 ± 9.5	31	25.9 (6.3–60.0)	20.6

ter release, and over half (51%) occurred within one year. Two males were struck by vehicles more than six years post-release 13.2 and 19.7 km from their respective release site, and a female released at Pigeon River Fish & Wildlife Area (FWA) was killed in a beaver trap 7.8 km away nearly six years later. Mean number of mortalities from each site was 4.3 ± 2.2, which comprised from 8–36% ($\bar{x}$ = 16.7%) of the number of otters released per site.

Post-release field surveys.—We conducted 43 surveys between February 1996 and January 2001 and located otter sign on 31 (72%) routes in the 11 release sites sampled (Table 3). An average of 25.9% of the points visited on these 31 surveys had otter sign (range = 6.3–60.0%). Pigeon River FWA was the only release site not sampled; mean number of surveys at the remaining 11 sites was 3.9 (range = 1–9). Surveys were run an average of 2.5 years (*SD* = 1.9) after otters had been released, but most (81%) were conducted within four years. Eight surveys (19%) at Big Oaks NWR, Tippecanoe River State Park (SP), Etna Green, and Mallard Roost Wetland Conservation Area (WCA) were conducted only 11–23 days ($\bar{x}$ = 17.1) after otters had been released. Sign was detected on seven (88%) of these surveys at 0–60% ($\bar{x}$ = 28.3%) of the points. Otter sign, however, was also found at 0–45.7% ($\bar{x}$ = 16.9%) of the points on five of eight surveys (63%) at three sites (Etna Green, Big Oaks NWR, Muscatatuck NWR) that were sampled at least five years post-release. Overall detection rate at all sites averaged 20.6% and ranged from 10.3% at Big Oaks NWR to 30.3% at Tippecanoe River SP and the Little Blue River (Table 3).

Reports of otters and their sign.—We received 1107 sightings from 62 of Indiana's 92 counties; 223 reports were omitted because they were suspect or lacked sufficient information to assess their validity. The remaining 884 sightings occurred in 14 of 15 watersheds, but 849 (96%) originated from the six targeted watersheds. Otter sightings were confirmed in 48 counties, but 17 counties surrounding the 12 release sites accounted for 799 (90%) observations. Number of otters sighted ranged from 1–9 ($\bar{x}$ = 2.0), but sightings of single otters (*n* = 499, 56%) were most common.

Since December 1996, we documented 17 incidents from 13 counties in which otters were accidentally caught but released from snares or foothold traps set for other furbearers. Fifteen (88%) occurred an average of 9.7 km (range = 3.1–22.5) from a release site. The other two otters were trapped in the Kankakee and Whitewater watersheds, 32 and 47 km from the nearest release site, respectively.

Excluding post-release field surveys, 170 reports of otter sign were collected, mostly from licensed trappers or natural resources

Table 4.—Reproductive characteristics of yearling (1–2 y) and adult (>2 y) female river otters (*n* = 60) collected in Indiana, February 1998 to March 2006. Corpora lutea counts are minimum number that was detected in ovaries. Corpora lutea were present but not counted in one adult.

Age class	No. examined	Corpora lutea			Blastocysts			Implanted embryos		
		n	Mean ± *SD*	Range	*n*	Mean ± *SD*	Range	*n*	Mean ± *SD*	Range
Yearling	26	13	2.62 ± 1.04	1–5	6	1.83 ± 0.75	1–3	2	4.00 ± 1.41	3–5
Adult	34	29	2.86 ± 0.99	1–4	8	2.50 ± 1.07	1–4	14	2.93 ± 1.07	1–4
Combined	60	42	2.79 ± 1.00	1–5	14	2.21 ± 0.98	1–4	16	3.06 ± 1.12	1–5

personnel, from 27 counties. Twelve counties, most of which surrounded the six release sites in northern Indiana, accounted for 138 (81%) reports.

Recovery of untagged otters.—A total of 206 (111♂:95♀) untagged otters (i.e., non-founder individuals) was reported killed in 47 Indiana counties through December 2005. Cause of death was incidental trapping (*n* = 131), collisions with vehicles (*n* = 68), drowning (*n* = 5), and unknown factors (*n* = 2). Age data were available for 198 otters (105♂:93♀); distribution by age class was 54 juveniles (27.3%; 20♂:34♀), 64 yearlings (32.3%; 38♂:26♀), and 80 adults (40.4%; 47♂:33♀). The age of five additional males could not be distinguished between yearling and two-year-old due to indistinct or irregular cementum patterns.

Most untagged otters (*n* = 177; 86%) were killed in the Muscatatuck, Patoka, St. Joseph, Tippecanoe, and upper Wabash watersheds. Similarly, 14 counties near release sites (Cass, Dubois, Fulton, Gibson, Huntington, Jackson, Jennings, Noble, Orange, Pike, Pulaski, Scott, Wabash, White) each had more than five mortalities that comprised 67% (*n* = 138) of the total kill statewide.

Evidence of reproduction.—Fifty-two of 884 sightings (5.9%) were of otter family groups reported from 16 counties in eight watersheds. Thirty-seven reports (71%) originated from eight release sites including 20 at Muscatatuck NWR. Family groups were sighted each year except for the first release year (1995). Group size averaged 4.2 otters (range = 3–8) and was typically comprised of one or two adults and 2–5 juveniles (x̄ = 2.9).

Untagged juvenile and yearling otters, definitive proof of successful reproduction, were recovered in 36 counties and 12 of 15 watersheds statewide. Most (69%), however, were taken in three of the six targeted watersheds (Patoka, Tippecanoe, upper Wabash). Five counties (Dubois, Fulton, Huntington, Pike, Wabash) surrounding six release sites each had over nine recoveries that accounted for 39% of the total. Untagged otters less than two years of age were also killed in eight counties in six non-targeted watersheds: Kankakee (Laporte, Starke), lower West Fork of the White (Knox), Maumee (Allen), upper East Fork of the White (Decatur), Wabash—main stem (Parke), and Whitewater (Ohio, Switzerland). Lastly, we were encouraged by the high proportion of young otters recovered each year in Indiana. An average of 58% of the untagged, known-age otters killed each year were < 2 years old. Juveniles were recovered as early as March 1996 and comprised 0–100% (x̄ = 33%) of the annual total; yearlings consisted of 0–73% (x̄ = 25%).

We examined fresh, whole reproductive tracts from 64 non-juvenile females for presence and number of corpora lutea, blastocysts, and embryos. Placental scars were evident in four post-partum tracts collected between 15 March and 8 May. Of the remaining 60 tracts, corpora lutea were present in 13 of 26 (50.0%) yearlings and 30 of 34 (88.2%) adults (Table 4). The degraded condition of ten tracts precluded complete counts of the number of corpora lutea; thus, minimum number of corpora lutea per female averaged 2.62 (*SD* = 1.04) and 2.86 (*SD* = 0.99) for yearlings and adults, respectively. Blastocysts were recovered from six of 11 (54.5%) yearling and eight of 15 (53.3%) adult females that had ovulated and did not contain implanted embryos. Mean number of blastocysts per female, however, was only 2.21 (*SD* = 0.98). Litter size based on counts of implanted embryos (*n* = 16) and post-partum placental scars (*n* = 4) averaged 3.25 (*SD* = 1.12). Most females (63%) with implanted embryos were taken from mid-December through mid-January and had uterine swellings to indicate embryonic development. Mean crown-rump length (CRL) of 12 embryos from three females killed between 31 December and 24 January was 1.94 ± 0.83 cm (range = 1.10–3.21). Two adults killed on 13 January and 3 March each contained four embryos averaging 7.83 ± 0.30 cm (range = 7.45–8.27) in CRL. Four male fetuses near full term were recovered from an adult killed on 2 March; they averaged 12.27 cm in CRL and weighed 120–130 g (x̄ = 125.5). Another adult killed on 7 March contained three fetuses (1♂:2♀) averaging 23.1 cm in total length and weighing 160–166 g (x̄ = 162.7).

Cumulative distribution and range expansion.—We used field surveys, sightings, and information from mortalities to assess the distribution and post-release range expansion of river otters in Indiana. Using all data sources (*n* = 1328 post-release records), otters were reported from 65 of 92 counties during the 11-year period between January 1995 and December 2005 (Fig. 2). We also received, but later omitted, 15 unconfirmed reports from nine additional counties (Clinton, Dearborn, Floyd, Hamilton, Hancock, Monroe, Putnam, Rush, Wayne). Otters occurred in 14 of 15 watersheds, but 94% of the records originated from the Muscatatuck, Patoka, southcentral Ohio, St. Joseph, Tippecanoe, and upper Wabash River watersheds. The only watershed from which otters were not reported was Lake Michigan in extreme northwest Indiana.

River otters are widely distributed throughout northeast, northcentral, and southern Indiana but are most prevalent in 15 counties surrounding the 12 release sites (Fig. 2). These top counties each had more than 20 records (x̄ = 71.9; range = 21–320) that accounted for 81% of all records and probably support the highest densities of otters in the state. Eleven adjacent counties (Cass, Crawford, Dubois, Gibson, Harrison, Jefferson, Miami, Posey, Scott, Starke, White) had 10–19 records (x̄ = 13.3); they too have relatively high otter numbers, most likely due to dispersal from nearby core populations. Otters are present, but less common, in nine counties that had 4–9 records (x̄ = 6.0). Excluding Marion and Newton counties, most lie on the periphery of the six priority watersheds. We consider otters rare in 30 counties in which there were from 1–3 records. Most of these counties, as well as those from which otters were not reported (*n* = 27), are in central Indiana (Fig. 2) where land use is typified by human development, urbanization, and widespread agricultural activity. Johnson & Madej (1994) considered watersheds in central Indiana less suitable for restoration, and the few scattered records in this region probably represent transient otters rather than re-established populations. Nonetheless, several larger waterways (e.g., east and west forks of the White River) and their major tributaries had at least 12 records, which suggests some pioneering individuals had colonized these lower priority systems.

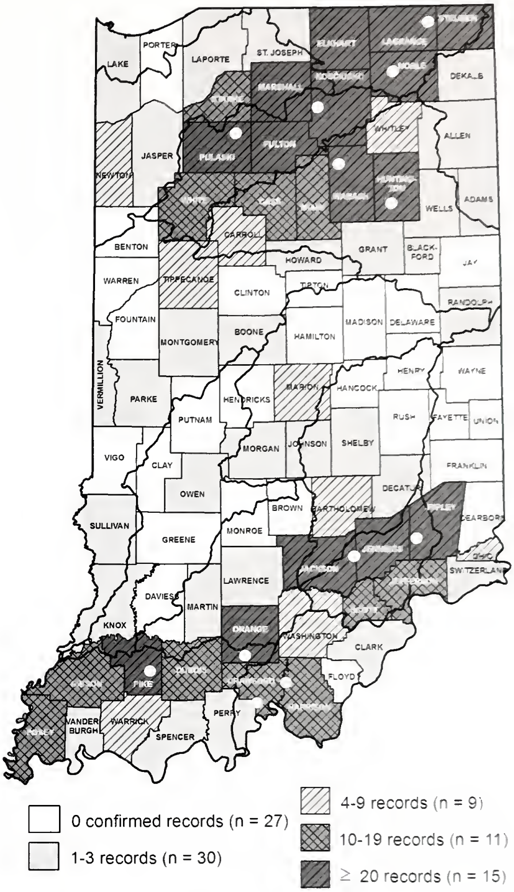

Figure 2.—Cumulative distribution by county of post-release records of river otters in Indiana (*n* = 1,328) from 1995 through 2005. White circles (○) represent release sites (*n* = 12). Thick black lines delineate watersheds (*n* = 15).

DISCUSSION

Otter mortality.—As expected, human-induced factors were significant sources of mortality for river otters in Indiana. Incidental trapping and collisions with vehicles accounted for 61.1% (n = 157) and 32.3% (n = 83), respectively, of 257 mortalities reported in this study. These were also key factors in other state restoration programs (Erickson & Hamilton 1988; McDonald 1989; Bluett et al. 1999; Serfass et al. 1999).

Beavers often enhance conditions for otters because their impoundments create wetland habitats, foraging opportunities, and den sites (Tumlison et al. 1982; Melquist & Hornocker 1983; Dubuc et al. 1990). Otters are particularly vulnerable to beaver trapping (Lehman 1979), yet no special regulations or restrictions were enacted to protect them from accidental take in traps legally set for other furbearers. To minimize losses, however, trappers were encouraged to voluntarily employ methods less likely to take otters, and where possible, otters were released on public properties that already restrict trapping (e.g., Big Oaks NWR, Muscatatuck NWR, Tippecanoe River SP). Nonetheless, sets for beaver accounted for 78% (n = 123) of all trap-related mortalities. Otters were most often killed in body-gripping traps (n = 91) and foothold traps in submergent sets (n = 28) for beaver. Thirty otters (19%) were taken in traps targeting raccoon (*Procyon lotor*). Although incidental trapping was the leading source of mortality in nine of 11 years, losses in the first five years were few ($\bar{x}$ = 4.4/year; range = 0–8) and did not hinder the eventual re-establishment of otters.

Drowning by entanglement in commercial fishing nets is another important source of otter mortality (Mowbray et al. 1979; Anderson & Woolf 1984; Erickson & Hamilton 1988; Bluett et al. 1999). Only four otters (less than 2% of all mortalities) drowned in nets set in Indiana waters, probably because these devices are restricted to the Ohio River and lower to middle reaches of the Wabash, Patoka, and East and West Forks of the White River. Sugar Ridge FWA was our only release site in waterways open to commercial fishing, and two males drowned in a 1.3-km reach of the Patoka River *ca.* 7 km upstream of this site. The other two mortalities occurred in the middle (Vermillion County) and lower (Posey County) reaches of the Wabash River bordering Illinois.

We observed a significant increase (t = 5.82, $P < 0.01$) in the number of mortalities after releases concluded in 1999 (Fig. 3). Between 1995 and 1999, an average of 9.8 (SD = 3.3) otters was reported killed annually; this figure increased to 36.0 (SD = 9.5) in the following six years. Concurrently, the percentage of tagged otters recovered each year declined steadily from a high of 83% (5 of 6 mortalities) in 1995 to only 2% (1 of 41) by 2005. Both trends were considered further proof that otter populations in Indiana were growing and reproducing as anticipated.

Reproductive success.—Excluding 1995, reproduction was confirmed each year, either by recovery of untagged otters and/or observations of family groups. Successful reproduction was ultimately documented at 11 of 12 release sites, often in successive seasons, and other streams statewide. The Little Blue River in the southcentral Ohio River watershed was the only release site at which recruitment was not confirmed. It is a smaller (66 km total length), undisturbed stream in a relatively isolated, sparsely populated region of southern Indiana. Human use is sporadic and mostly limited to occasional recreational pursuits (e.g., canoeing, sport fishing). We compiled only ten records in the Little Blue River since the 1999 release, eight of which were from field surveys. Otter sign, however, was still evident, including at the release site, in 2001 and 2004. Few sightings and lack of reproductive evidence were likely a result of little human presence rather than failure of otters to repopulate the Little Blue River.

Based on presence of corpora lutea, ovulation rates of 88% and 50% were obtained for adult and yearling otters, respectively. Comparable rates were reported for adults from Oregon (98%; Tabor & Wight 1977), Maryland (65%; Mowbray et al. 1979), Maine (77%; Docktor et al. 1987) and Missouri (84%; Hamilton 1998). The reproductive potential of yearling females, however, is less certain. Early studies (Liers 1951; Hamilton & Eadie 1964; Tabor & Wight 1977) concluded female otters do not breed until two years of age. Liers (1958) later reported conception by a 15-month-old female, and others have since reported pregnancy rates in yearlings of

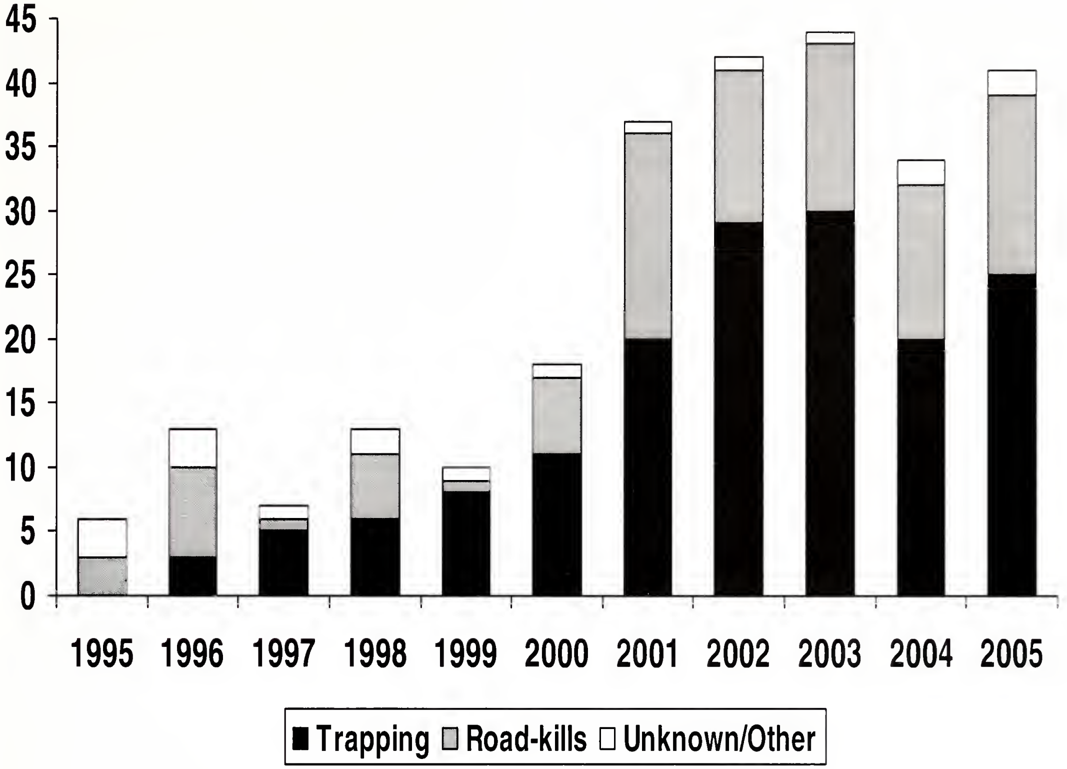

Figure 3.—Number and source of river otter mortalities annually in Indiana, 1995–2005.

7.1% (Mowbray et al. 1979), 33% (Docktor et al. 1987), and 43% (Hamilton 1998). Because otters exhibit delayed implantation, these females would have mated when they were *ca.* 12 months old and subsequently produced their first litter in the spring near the end of their second year. No corpora lutea were found in the ovaries of 27 juvenile females, but two killed between 2–13 March (i.e., *ca.* 11+ months old) each contained three Graafian follicles indicating they had recently ovulated.

Regardless of age class, fewer blastocysts were often recovered from uteri than corpora lutea counted in matching ovaries. This difference is almost certainly due to blastocysts being lost during flushing or destroyed by autolysis, desiccation, and/or poor preservation. Thus, productivity estimates based on blastocysts were biased low when compared to those obtained from corpora lutea and embryo counts (Table 4) as also reported by Chilelli et al. (1996). Although rates of intrauterine mortality appear low in otters (Tabor & Wight 1977; Mowbray et al. 1979), embryo counts still provide the most reliable estimate of litter size (Chilelli et al. 1996). Our estimates, based on either embryo counts ($\bar{x}$ = 3.06; *SD* = 1.12; n = 16) or post-partum placental scars ($\bar{x}$ = 4.00; *SD* = 0.82; n = 4), compare favorably with those obtained elsewhere. For example, litter size averaged 2.68 in Alabama and Georgia (Hill & Lauhachinda 1981), 2.73 in Maryland (Mowbray et al. 1979), 2.75 in Oregon (Tabor & Wight 1977), and 3.44 for newly restored and increasing populations in Missouri (Hamilton 1998).

Swellings signifying implantation had occurred were noted in the uteri of nine females killed from 28 November to 1 February. The early date may be an anomaly because the tract was from an adult female transported from Louisiana 22 months earlier. Mean date for the eight remaining tracts was 3 January, which suggests parturition in Indiana otters, assuming a 61–63 day gestation period (Larivière & Walton 1998), is well underway by early March and likely extends into April. The reproductive histories of several females further support this timeline. Three fetuses near full-term were recovered from an adult killed on 7 March, and placental scars were visible in the uteri of females killed on 15 March (*n* = 2) and 21 April (*n* = 1). Their reproductive tracts were distended and their teats showed signs of lactation, suggesting they had recently given birth.

Monitoring restored otter populations.—River otters are inherently difficult to monitor because of their low population densities, high mobility, secretive nature, and use of poorly accessible habitats (Erickson & Hamilton 1988; Ralls 1990). These factors are likely exacerbated in the initial stages of restoration when numbers are inevitably low before populations become re-established. Our post-release field surveys were intended only to document presence and distribution near release sites; and otter activity was detected in each watershed sampled, including three sites that were visited five and six years post-release. Although most sign was near release sites, we also found evidence otters used adjacent habitats and other waterways in the six priority watersheds. Therefore, other drainages were surveyed in subsequent winters to improve the prospects of detecting emerging populations elsewhere in the state. Since 2002, these surveys still found otter sign in the six priority watersheds as well as the upper East Fork of the White, upper West Fork of the White, lower West Fork of the White, and Whitewater river watersheds.

Public interest and enthusiasm in otter restoration was keen during the release phase, which created a high profile atmosphere conducive to reporting of sightings, particularly near release sites where otters were visible. Bluett et al. (1999), however, cautioned frequency of observations depends on collection effort and changes in public sentiment as otters become established and less of a novelty. As anticipated, there was a steady decline in the number of observations reported annually after our releases concluded in 1999. Only 258 of 884 sightings (29%) were reported since 2000, including 26 in 2004 and 29 in 2005, the fewest during the 11-year study. We attribute this decline to waning public interest as otters became more commonplace and concur with Woolf et al. (1997) that sightings lose their utility as an effective tool to monitor otter populations over time.

Regional perspective.—River otters are highly mobile as demonstrated by eight individuals released in Indiana that were later recovered in adjacent states. Bluett et al. (1999, 2004) attributed immigration of otters from neighboring states of Iowa, Missouri, and Wisconsin contributed to population growth in Illinois. Dispersal of otters from Ohio and Maryland also facilitated range expansion in Pennsylvania (Serfass et al. 1999). Accordingly, we anticipate releases of over 700 otters in Illinois and Kentucky during the 1990s (Raesly 2001) to aid re-establishment in Indiana waterways bordering these states. In fact, otters possibly had already colonized the Kankakee River prior to our first release in northern Indiana in 1996. A male was trapped on LaSalle FWA in 1994, and otter sign was reported on the Kankakee River in Lake and Newton counties in 1996 and 1997. Although we compiled 22 records in the Kankakee watershed, it's possible that early reports, all within 15 km from Illinois, were from transient otters immigrating into Indiana along the Kankakee River. Additionally, releases in southeast Illinois (Bluett et al. 1999) may bolster recovery in western and southwest Indiana while releases in northern Kentucky may contribute to colonization of Ohio River tributaries in southern Indiana.

Legal status and considerations.—River otters were first given complete protection in Indiana in 1921 (Lehman 1982) and were subsequently listed as endangered by the Indiana Department of Natural Resources (IDNR) in 1969. The species' status was changed to extirpated in 1986, however, because conclusive evidence of a remnant population in the state was lacking. In 1994, the IDNR reclassified the otter as endangered in anticipation of forthcoming restoration efforts.

Endangered species are defined by statute (IC 14-2-8.5-1) as any species or subspecies of wildlife whose prospects for survival or recruitment within the state are in jeopardy or are likely to become so within the foreseeable future. The goal of Indiana's river otter restoration program was to re-establish otter populations in six priority watersheds. Although quantitative delisting criteria were not developed at the onset of the program, restoration efforts to date have met, and in some cases exceeded, the stated program goal. The six targeted watersheds accounted for 94% of the post-release records documented in this study.

Multiple lines of evidence indicate otters are consistently reproducing in these watersheds, and core populations surrounding release sites are self-sustaining and secure. Further, otters have expanded to adjacent habitats, colonized watersheds not initially targeted for restoration, and were documented in > 70% of Indiana's counties in the 11 years following the program's inception. These data indicate long-term prospects for maintaining healthy populations were favorable, and in 2005, the IDNR removed the river otter from endangered status in the state.

The rapid and widespread return of river otters to portions of Indiana was not unexpected. Strategies that were successful in the initial release at Muscatatuck NWR (Johnson & Berkley 1999) were used throughout the program. By 1995, releases in adjoining states had concluded or were nearing completion, and many programs were already reporting stable or growing otter populations (Raesley 2001). Such successes, however, may also generate unexpected social conflicts such as those experienced in Missouri with local sport-fishing interests, private pond owners, and aquaculture facilities (Hamilton et al. 2000). Few complaints have been received from anglers on the impacts, real or perceived, of otters on native sport fish populations in Indiana waterways. Reports of otter depredation from pond owners, however, are a more common and recent phenomenon (10 of 18 complaints since 2004). These ponds are typically small (*ca.* 1 ha) and often close to release sites where otter densities are likely highest. As restored populations continue to grow and expand, nuisance complaints at private ponds and aquaculture facilities in Indiana are likely to become more widespread and numerous.

Melquist & Dronkert (1987) described a comprehensive management program for river otters that included elements of conservation (e.g., reintroductions, habitat preservation, identification and control of limiting factors, regulation of mortality) and population regulation (e.g., sustained yield harvest, damage control). Thus far, otter management in Indiana has focused on the initial components of conservation, primarily reintroductions and protecting and monitoring restored populations. As otter numbers continue to increase as expected, management strategies should explore opportunities to regulate populations and alleviate legitimate depredation complaints where appropriate. Most midwestern U.S. states that reintroduced otters before Indiana (i.e., Missouri, Kentucky, Iowa, Ohio) have already enacted or proposed regulated harvests of restored populations. An average of 27.2 otters (range = 21–37) was reported accidentally trapped during the last five fur harvest seasons in Indiana, but the extent of unreported, trap-related mortalities is unknown. Key population monitoring activities, however, should continue to better define otter distribution and identify age-specific reproductive parameters. These data will become increasingly important as management strategies progress toward a more holistic approach of protection, maintenance, and regulation of restored otter populations.

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TERRESTRIAL MAMMALS OF THE NAVAL SUPPORT ACTIVITY (NSA CRANE) IN MARTIN COUNTY, AND OF THE CRANE DIVISION OF THE NAVAL SURFACE WARFARE CENTER (GLENDORA SITE) IN SULLIVAN COUNTY, INDIANA

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ABSTRACT. A total of 79 small mammals was trapped at Naval Support Activity Crane, Martin County, Indiana, including 23 short-tailed shrews (*Blarina brevicauda*), 21 least shrews (*Cryptotis parva*), 11 prairie voles (*Microtus ochrogaster*), 7 southeastern shrews (*Sorex longirostris*), 5 smoky shrews (*Sorex fumeus*), 4 meadow jumping mice (*Zapus hudsonius*), 3 white-footed mice (*Peromyscus leucopus*), 2 meadow voles (*Microtus pennsylvanicus*), 2 pygmy shrews (*Sorex hoyi*), and 1 bog lemming (*Synaptomys cooperi*). This assemblage constituted rather low abundance as related to the amount of trapping.

A total of 121 small mammals was trapped at the Crane Division, Naval Surface Warfare Center (NSWC Crane), Glendora Site, Sullivan County, Indiana, including 54 least shrews (*Cryptotis parva*), 38 prairie voles (*Microtus ochrogaster*), 11 prairie deer mice (*Peromyscus maniculatus bairdii*), 7 bog lemmings (*Synaptomys cooperi*), 6 meadow voles (*Microtus pennsylvanicus*), and 5 white-footed mice (*Peromyscus leucopus*). This assemblage constituted rather low biodiversity, probably because the area was small and of relatively uniform habitat. However, it was a very interesting assemblage as it might resemble that of drier portions of earlier prairie in this area, and it contained two species relatively uncommon in surveys, the least shrew and the bog lemming.

Keywords: Small mammals, Crane, Glendora, Martin County, Sullivan County, Indiana

Studies are conducted on many public properties to determine what species are present, to determine if endangered or threatened species are there, and to make management recommendations if appropriate (e.g., Whitaker 2004). Military bases may serve as natural history reserves because they are large, they are protected, and they often contain areas of natural habitat. Examples from Indiana are at Newport, Vermillion County (Veilleux et al. 1998; Vincent et al. 1998) and Camp Atterbury (mostly Bartholomew County, Whitaker et al. 2005). Some publications from bases from other states are by Brack et al. (in press, from Kansas) and by Brack & Duffy (2006, from Ohio).

Naval Support Activity Crane (NSA Crane) is large (approximately 25,900 ha) and is used for testing by the US Navy. It is in the unglaciated hill country of southern Indiana, and as such has numerous hills and ravines. Much of the area had been previously farmed and/or timbered, and most of it is currently forest. Glendora is a much smaller property consisting mostly of a lake constructed by the Navy for various kinds of testing, and of surrounding fields (Fig. 1).

The purpose of the present studies was to accumulate information on the small mammals of NSA Crane and Glendora, and particularly to determine if endangered or threatened species were present. Species of small mammals that might reasonably be expected to occur at NSA Crane (Mumford & Whitaker 1982) are the smoky shrew (*Sorex fumeus*), pygmy shrew (*S. hoyi*), southeastern shrew (*S. longirostris*), short-tailed shrew (*Blarina brevicauda*), least shrew (*Cryptotis parva*), eastern mole (*Scalopus aquaticus*), white-footed mouse (*Peromyscus leucopus*), prairie deer mouse (*Peromyscus maniculatus bairdii*), meadow vole (*Microtus pennsylvanicus*), prairie vole (*M. ochrogaster*), woodland vole (*M. pinetorum*), bog lemming (*Synaptomys cooperi*), house mouse (*Mus musculus*), and meadow jumping mouse (*Zapus hudsonius*).

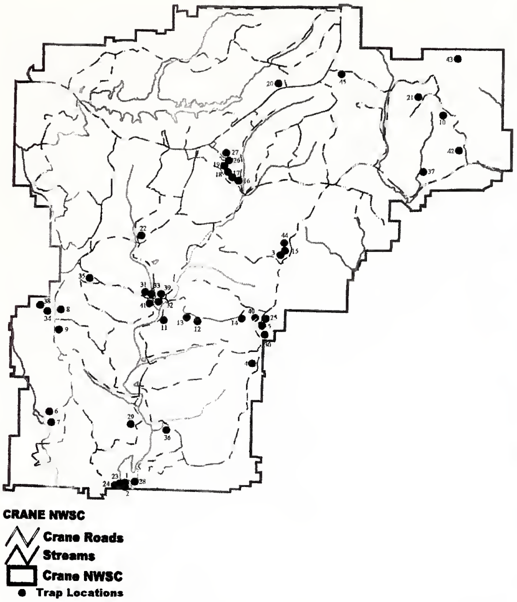

Figure 1.—Map of Crane Naval Surface Warfare Center, Martin County, Indiana. The area consists of 62,473 acres. The numbered dots are the sites of the trapping locations.

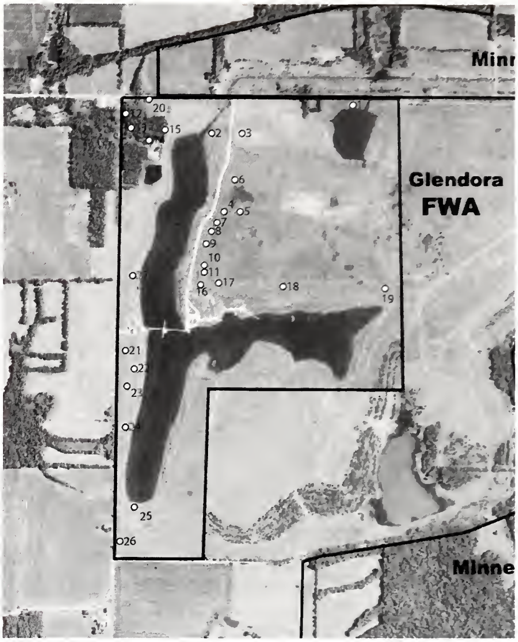

Figure 2.—Photo of the Crane Division, Naval Surface Warface Center (NSWC Crane), Glendora Site, Sullivan County, Indiana. The area consists of 187 hectares. The numbered dots are the sites of the trapping locations.

The same species would be expected at Glendora except for *Sorex hoyi* and *Sorex fumeus*, which occur only in the unglaciated hills of south central Indiana. In addition, the masked shrew would be expected at Glendora but not at Crane, as it occurs throughout the state except in the unglaciated hills.

NSA Crane includes a total of 25,900 ha in northern Martin County, Indiana (Fig. 1). NSA Crane provides a variety of weapons development, testing and manufacturing for the Navy, Army, Air Force and Marine Corps. It includes a large lake (Lake Greenwood) of about 324 ha, plus some smaller lakes (Lake Gallimore and Seed Tick Reservoir). Most of the terrestrial part of the study area is forested (7953 ha, 19,653 acres). There are a few dry grassy/weedy old fields, and isolated moist fields and a few marshy areas are also present.

The Crane Division, Naval Surface Warfare Center (NSWC Crane), Glendora Site includes a total of 187 ha, including a lake of about 36 ha, plus some smaller ponds, just northeast of Sullivan Lake, Sullivan County, Indiana (Fig. 2). It is used for testing various US Navy equipment and weapons. There is a small wooded area (about 4 ha) in the northwest corner of the property. Most of the terrestrial part of the study area is composed of dry grassy/weedy old field, although isolated moist fields and marshy areas are also present. The areas, normally moist, were very dry at the time of the study.

METHODS

Crane (Martin County).—Small, snap-back mousetraps, rat traps, and pitfall traps (sunken cans) were used to sample the small mammals at NSA Crane. An attempt was made to sample the major habitats present, dry old field (grassy and/or weedy), moist old field, marshy areas, and wooded areas, and to trap for all of the species that might be present. Traps were set in 45 different lines (Fig. 1). The majority of the mousetrap lines contained 100 traps. Lines in the woods were directed at woodland voles, and, therefore, were set crosswise in underground burrows at the level of the floor of the burrow and covered with bark. These lines contained 45 or 50 traps. The pitfall lines contained 5, 10, or 15 sunken cans and the rat trap lines contained 12 or 13 traps per line. For comparison, data were summarized as number trapped per 100

Table 1.—Small mammals trapped at NSA Crane, Martin County, Indiana. TN = trap-nights.

	Dry field 27 lines 9200 TN	Moist field 5 lines 2000 TN	Woods 7 lines 785 TN	Pitfalls 6 lines 345 TN	Total 45 lines 12330 TN
Blarina brevicauda	7	3	3	10	23
Cryptotis parva	16	5	0	0	21
Sorex longirostris	0	0	0	7	7
Sorex fumeus	0	0	0	5	5
Sorex hoyi	0	0	0	2	2
Peromyscus leucopus	1	0	1	1	3
Zapus hudsonius	3	1	0	0	4
Synaptomys cooperi	1	0	0	0	1
Microtus pennsylvanicus	1	1	0	0	2
Microtus ochrogaster	9	2	0	0	11
Total	38	12	4	25	79
(No/100TN)	(0.41)	(0.6)	(0.51)	(7.25)	(0.64)

trap-nights, a trap-night being one trap for one night.

Glendora (Sullivan County).—At Glendora, only snap-back mouse traps were used. Traps were set in 27 different lines in which an attempt was made to sample the major habitats present, dry old field (17 lines), moist field and marshy areas (6), and the wooded area (4). The first two lines included 191 and 155 traps, and the remainder contained 100 traps per line. Again, data were summarized as number trapped per 100 trap-nights. Observations were made of larger mammals or their sign while trapping occurred.

RESULTS AND DISCUSSION

NSA Crane (Martin County).—A total of 79 small mammals of 10 species was collected at NSA Crane between 24 August and 28 October 2005 (Table 1). By order of decreasing abundance, they were *Blarina brevicauda* (23 individuals), *Cryptotis parva* (21), *Microtus ochrogaster* (11), *Sorex longirostris* (7), *Sorex fumeus* (5), *Zapus hudsonius* (4), *Peromyscus leucopus* (3), *M. pennsylvanicus* (2), *Sorex hoyi* (2), and *Synaptomys cooperi* (1).

Most of the lines (32 of 45) trapped during this work were in dry or moist open field (including marshy field). Seven lines were in woods, and six were pitfall lines in woods (Table 1).

The 27 lines in dry field yielded all of the species taken except for *Sorex fumeus*, *S. hoyi*, and *S. longirostris*. The major species in the dry old field were *Cryptotis parva* (16), *Microtus ochrogaster* (9), and *Blarina brevicauda* (7), *Zapus hudsonius* (3), and single individuals of *Peromyscus leucopus*, *Synaptomys cooperi*, and *M. pennsylvanicus*. The five lines in moist fields yielded *C. parva* (5 individuals), *B. brevicauda* (3), *M. ochrogaster* (2), *M. pennsylvanicus* (1), and *Z. hudsonius* (1).

The seven snap trap lines in woods yielded only one *P. leucopus* and three individuals of *B. brevicauda*. The six pitfall lines in the woods yielded five species of small mammals including *B. brevicauda* (10 individuals), *S. longirostris* (7), *S. fumeus* (5), *S. hoyi* (2), and *P. leucopus* (1).

In addition to the animals trapped, several other species were documented on the property. Eastern mole (*Scalopus aquaticus*) burrows were seen when trapping in the wooded areas. Cottontail rabbit (*Sylvilagus floridanus*) droppings were seen when trapping in the field sites. Chipmunks (*Tamias striatus*), fox squirrels (*Sciurus niger*), and gray squirrels (*Sciurus carolinensis*) were seen and heard on several occasions. A road-killed fox squirrel was collected on 21 October 2005. Coyotes (*Canis latrans*) and white-tailed deer (*Odocoileus virginianus*) were seen on many occasions. An opossum (*Didelphis virginiana*) was seen dead on the road at the north end of the property. Raccoon (*Procyon lotor*) tracks were seen on several occasions. In addition to this survey, one of the authors (SJ) supplied his data on mammals taken during radio-tracking work on bobcats (*Lynx rufus*) (Table 2).

Table 2.—Mammals trapped at NSA Crane (Martin County) by Scott Johnson between early December and early April, 1998–2005.

Species	Number trapped
Didelphis virginiana (Opossum)	629
Procyon lotor (Raccoon)	333
Lynx rufus (Bobcat)	62
Mephitis mephitis (Striped Skunk)	33
Sylvilagus floridanus (Eastern Cottontail)	20
Canis latrans (Coyote)	18
Canis familiaris (Domestic Dog)	2
Felis catus (Domestic Cat)	1
Urocyon cinereoargenteus (Gray Fox)	1
Vulpes vulpes (Red Fox)	1
Sciurus carolinensis (Grey Squirrel)	1
Sciurus niger (Fox Squirrel)	1

Many of the interesting small mammals are found in grassy fields, so the majority of our trapping occurred there. However, field habitats were rather scarce, were isolated from each other, and many were mowed. For these reasons, and probably because of the dryness, fewer mammals were trapped than expected. Also, there were no cultivated fields on the property, which is probably the reason we did not collect any prairie deer mice (*Peromyscus maniculatus bairdii*) or house mice (*Mus musculus*).

Another species that is very likely present at NSA Crane is the woodland vole (*Microtus pinetorum*). Although rather uncommon, it is usually found in soft moist soil in woods, but we found few areas of that sort on the property. Efforts to capture this species were not successful.

The number of small mammals trapped was small, possibly due to the area being rather uniformly forested. The species most commonly found in woods in southern Indiana is *P. leucopus*. We did not set traps specifically for this species, but were surprised that only three were captured, as this is probably the most common small mammal at NSA Crane. On the other hand, two species of shrews, *S. fumeus* and *S. hoyi*, first taken in Indiana in 1982 in unglaciated hill country of south central Indiana (Caldwell et al. 1983), are restricted in the state to that area (Cudmore & Whitaker 1984; Whitaker & Cudmore 1988). Crane is towards the northern edge of that area, and both species were documented during this study.

Cryptotis parva is seldom taken in large numbers, but surprisingly was the second most commonly taken species at NSA Crane. This was quite surprising since it is a species of the dry grasslands, and the property is mostly wooded. Likewise, *Synaptomys cooperi* is seldom taken, partly because it is not generally attracted to bait, and partly because, despite its name (bog lemming), it is usually found in dry grassy fields, especially of little bluestem. One *S. cooperi* was trapped in this survey. *Microtus ochrogaster* is the dominant vole species in dry grassy areas, and not surprisingly, was the third most abundant species at NSA Crane. On the other hand, *M. pennsylvanicus* is found in moist grassy vegetation; and only two were trapped during this study.

Glendora (Sullivan County).—A total of 121 small mammals of six species was collected in small mammal traps at Glendora between 23 May and 8 July. By order of de-

Table 3.—Small mammals trapped at Crane Division, Naval Surface Warfare Center (NSWC Crane), Glendora Site, Sullivan County, Indiana. TN = trap-nights.

	Old field 17 lines 5538 TN	Moist field 6 lines 1800 TN	Woods 4 lines 1200 TN	Total 27 lines 8538 TN	No/100 TN
Cryptotis parva	48	6	0	54	0.63
Peromyscus maniculatus	3	8	0	11	0.13
Peromyscus leucopus	0	2	3	5	0.06
Synaptomys cooperi	7	0	0	7	0.08
Microtus pennsylvanicus	0	6	0	6	0.07
Microtus ochrogaster	35	3	0	38	0.45
Total	38	12	4	79	
(No/100TN)	(0.69)	(0.67)	(0.33)	(0.93)	

creasing abundance, they were *Cryptotis parva* (54 individuals), *Microtus ochrogaster* (38), *Peromyscus maniculatus bairdii* (11), *Synaptomys cooperi* (7), *Microtus pennsylvanicus* (6), and *Peromyscus leucopus* (5).

Evidence of larger terrestrial mammal species was noted as follows. Two cottontail rabbits (*Sylvilagus floridanus*) as well as several piles of droppings were seen. Chipmunks (*Tamias striatus*) were seen on two occasions, one in the woods in the northwest portion of the area and another just outside that area across the road to the north. A coyote (*Canis latrans*) was seen in late morning on 24 May in a cornfield just west of the property. An opossum (*Didelphis virginiana*) was seen dead on the road just north of the property.

The number of species of mammals trapped was small probably due to the uniform habitat of the area, made up mostly of grassy fields with mixed forbs, and small areas of shrubby field. The only wooded portion was a few hectares in the northwest corner.

Most of the trap lines (total 21 of 27) were set in dry or moist open fields because this was by far the dominant habitat. Two lines were in marsh, and four were in woods (Table 1). The 21 lines in dry or moist fields yielded all of the species taken except for *M. pennsylvanicus* and *P. leucopus*. The major species in the dry old field were *C. parva*, *M. ochrogaster*, and *S. cooperi*, along with a few individuals of *P. maniculatus bairdii*. The two lines in a marshy field yielded all six individuals of *M. pennsylvanicus*, which is a marsh/moist field inhabitant.

The four lines in woods yielded only three *P. leucopus*. This is probably because the woods were so dry and also it was hard-packed soil. Other species that might be present but were not captured at Glendora are the meadow jumping mouse (*Zapus hudsonius*), the pine vole (*Microtus pinetorum*), the short-tailed shrew (*Blarina brevicauda*), the masked shrew (*Sorex cinereus*), and the southeastern shrew (*S. longirostris*). We were surprised not to find *Blarina brevicauda*, *S. cinereus*, *S. longirostris*, and *Z. hudsonius* in the moist areas, but this may have been because of the reduced amount and relatively isolated nature of these areas, plus the fact that even the moist habitats tended to be very dry during the study period. *Blarina brevicauda* is usually rather abundant in woods, but even the woods were very dry. *Microtus pinetorum* is rather uncommon and is usually found in soft moist soil in woods, but we did not find soil of that sort in the study area.

Cryptotis parva is seldom taken in numbers, but was the most commonly taken species at Glendora. This was not altogether surprising since it is a species of the dry grasslands. Likewise, *S. cooperi* is seldom taken, partly because it is not generally attracted to bait, and partly because, despite its name, it is usually found in dry grassy fields, and often in little bluestem. *Microtus ochrogaster* is a dominant species in dry grassy areas and was the second most abundant species at Glendora. *Microtus pennsylvanicus*, on the other hand, is found in moist grassy vegetation, thus the reduced numbers. *Peromyscus maniculatus bairdii* occurs most commonly today in areas with little ground cover, primarily in cultivated fields. We have often wondered where this species occurred in the days of prairies with great amounts of vegetation. We think this species occurred sparingly because, although there was much vegetative ground cover, there were some areas with reduced vegetation.

Indiana originally contained much grassy old field habitat (prairie), and operations at Glendora have restored habitat resembling original prairie. This property may give a picture of the small mammal community of the prairies that used to be common in west central Indiana. *Microtus ochrogaster* would probably have been the dominant small mammal in the prairie environment. This species is cyclic, forming higher populations every three or four years, and we expect it was on the lower end of the cycle at the time of our study. It would be very interesting to study this community over several years to see how the various species inter-relate. *Microtus ochrogaster* and *S. cooperi* may have been the principal pure herbivores in this community, with *C. parva* being the principal carnivore. Since there is relatively little habitat of this type in Indiana, and since we think the small mammal community resembles that of drier parts of the original prairie, we recommend that the grassy nature of the area be maintained by mowing and/or fire. During this process it would also be beneficial to attempt to reduce the amount of fescue, and to increase the native grasses.

Results from the two studies can be compared. Trapping at Glendora resulted in 121 small mammals trapped in 8538 trap nights (TN), or 1.42 per 100 TN, as compared to 79 small mammals in 12,330 TN, for a total of only 0.64 per 100 TN. This difference was significant ($\chi^2 = 31.44$, 2 *df*).

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SKELETAL CHARACTERS AND THE SYSTEMATICS OF ESTRILDID FINCHES (AVES: ESTRILDIDAE)

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ABSTRACT. The family Estrildidae contains 108 to 140 species arranged in 15 to 40 genera and two to nine tribes or subfamilies. In this study 401 skeletons belonging to 103 species and 27 genera were compared, as well as 75 skeletons of 15 genera of possibly related forms; skeletal characters add to the existing characters of behavioral, external anatomical, and molecular features. Best skeletal characters for generic separation were shape of the caudal basibranchial and a combination (PCA) of mensural characters. *Pholidornis* is not an estrildid. The classification of Goodwin (1982) was affirmed with these changes: Tribes should be dropped. The genus *Lepidopygia* should be lumped in *Lonchura*. Additional taxonomic changes are cautiously suggested.

Keywords: Wax-billed finches, Africa, Australia, southern Asia, Indo-Pacific islands

The finches studied here have variously been called waxbills, grass finches, manikins, munias, etc. They inhabit Africa, Australia, southern Asia, and the Indo-Pacific islands, and have been widely kept and studied in aviaries worldwide. From 108–140 species of Estrildidae, arranged in 15–40 genera, are recognized by recent authorities. Three tribes (or subfamilies) are usually recognized, although several genera have been moved back and forth amongst those tribes. External anatomy (including patterns of mouth spotting in nestlings), behavioral patterns, presence or absence of nessoptiles, appendicular myology, chromosomal configurations, and chemical analysis of proteins and DNA (both nuclear and ribosomal) have been used as characters for classification of species, genera, and tribes. Biochemical studies were those of Kakizawa & Watada (1985), Christidis (1987), Sorenson & Payne (2001, 2002), Payne & Sorenson (2003), Sorenson et al. (2004), and Van der Meij et al. (2005). The addition of a set of skeletal characters should help clarify relationships.

Complete classifications which may be called modern were these: Delacour (1943) recognized 15 genera and 108 species, grouping them into three tribes, Estrildae, Poephilae, and Lonchurae. (Hereafter, these tribal names are more correctly spelled Estrildini, Poephilini, and Lonchurini.) Wolters (1957) recognized 31 genera. Steiner (1960) recognized 9 tribes and 33 genera. Mayr (1968) recognized 25 genera, but did not list every species; he utilized Delacour's three tribes, but moved four genera to different tribes. Mayr, Paynter & Traylor (1968) recognized three tribes and 27 genera. Goodwin (1982) recognized 27 genera and 132 species—not quite the same genera as in Mayr et al., for he split one of their genera (*Lonchura*) and lumped another (*Padda*); he did not explicitly recognize tribes. Sibley & Monroe (1990) recognized 29 genera, although they mentioned as generic characters only the DNA work of Sibley & Ahlquist (1990) on three genera and four species and the protein electrophoresis work of Christidis on 16 genera. In a series of papers, Sorenson & Payne (2001, 2002), Payne & Sorenson (2003), and Sorenson et al. (2004), using mitrochondrial DNA, studied 74 species and 26 genera (also 12 more genera they recognized, but which Goodwin 1982 did not). Sorenson et al. (2004) grouped the family into two major clades, a primarily African one (= Estrildini) and a primarily Australasian one (= Poephelini and Lonchurini); the former they divided into three clades and the latter into two or three in their next two steps.

Systematic studies at the generic level but omitting several genera included: Wolters (1950, 1966) reviewed the African genera. Güttinger (1970) revised *Lonchura* using behavioral characters. Ziswiler, Güttinger & Bregulla (1972) revised *Erythrura* using behavioral and external anatomic characters. Güttinger (1976) reviewed two genera using behavioral characters. Bentz (1979) studied 23 genera using appendicular muscle characters. (Bentz raised the taxonomic level of the three tribes to subfamilies.) Kakizawa & Watada (1985) studied protein electrophoresis of 20 genera; they reduced the number of tribes from three to two, lumping Poephilini with Lonchurini. Christidis (1986, 1987) studied the chromosomes and proteins of 16 genera; he recognized the three tribes but moved *Aidemosyne* to a different one. Baptista et al. (1999) studied seven genera using protein eletrophoresis, palate markings of nestlings, neossoptile distribution, bill shape, and six behavioral characters; they split *Lonchura* into two genera, lumped *Padda* into one of these, and moved *Amadina* from Lonchurini to Estrildini. Schodde & Mason (1999) reclassified the 20 Australian species into eight genera; they lumped *Aegintha*, *Aidemosyne*, *Chloebia*, and *Padda* into various genera, but split *Emblema* into two genera (*Emblema* and *Stagonopleura*) and *Poephila* into two genera (*Poephila* and *Taeniopygia*). Also, they split *Heteromunia* off from *Lonchura*. Van der Meij et al. (2005) studied 12 genera using mitochondrial and nuclear DNA.

Many workers have investigated the relationships of the Estrildidae to other major suprageneric groups. Sibley & Ahlquist (1990) gave a thorough summary. Sushkin (1927) concluded that the waxbills were most closely related to the whydahs (*Vidua*), but belonged as a subfamily in the Ploceidae. Tordoff (1954) on the basis of skull characters placed the Estrildinae in the Ploceidae, near the Carduelinae. Friedmann (1960, 1962) concurred with Sushkin. Ziswiler (1967) studied the structure of the alimentary canal of various seed-eating birds (including two species of whydahs and nine species of eight genera of estrildids). He found estrildids uniform among themselves and distant from Ploceidae (including Viduinae) and Fringillidae. Foelix (1970) studied the salivary glands of seed-eating birds (not including any whydahs); he found the estrildids uniform among themselves and distinct from Ploceidae and Fringillidae. Ziswiler (1979) from a study of the stiffening devices of the tongue confirmed his earlier position that the Emberizidae, Ploceidae, and Estrildidae had evolved the seed-eating adaptation separately. Christidis (1986, 1987) on the basis of chromosome and protein electrophoresis work placed the estrildids closer to the Ploceidae than to any other group. Sibley & Ahlquist (1990) and Sibley & Monroe (1990) on the basis of their DNA studies placed the estrildids and whydahs (two species studied) in one subfamily of Passeridae and the sparrows and weavers in other subfamilies. Cramp & Perrins (1994) characterized the Estrildidae, Passeridae, and Ploceidae, placing the Bubalornithinae in Ploceidae and Viduinae in Estrildidae. Schodde & Mason (1999) included several skeletal characters in their characterization of Estrildidae. Sorenson & Payne (2001, 2004) on the basis of mitochrondrial DNA studies, concluded that the estrildids and viduins had evolved together, separate from the ploceids and passerids. Lahti & Payne (2003), followed by Fry & Keith (2004) moved *Anomalospiza* from Ploceidae to Estrildidae, Viduinae, on the basis of anatomy and behavior, concluding that it was a fairly close relative of *Vidua*.

From all of the literature review above, one poorly-known genus, *Pholidornis*, which has sometimes been placed in Estrildidae, has been excluded (Traylor 1968, Vernon & Dean 1975, Sefc et al. 2003).

METHODS

Skeletons of 401 individuals belonging to 103 species and 27 genera of Estrildidae were examined. In addition, 23 skeletons of eight species of Viduinae and 52 skeletons of 22 species of 13 genera of Ploceidae (two genera of Bubalornithinae, five of Passerinae, and six of Ploceinae) were compared. The classification of Goodwin (1982) is used in this paper for Estrildidae except where otherwise stated. Outside Estrildidae, the classification of Moreau & Greenway (1962) in *Check-list of Birds of the World* is used, except for the genera *Pholidornis* and *Anomalospiza*.

Fifty-one characters (measurements, ratios between measurements, and shapes of bony parts) were tabulated for each specimen. Of course, as a result of broken or missing bones or my inadvertence, a few data on some specimens were not recorded. On arithmetical characters the figure used for a species is a mean of the specimens measured. Of these, 20 characters were arithmetical and complete enough to be used in a principal components

Table 1.—Best generic characters observed in Estrildidae. For explanation, see text, pages 92–94.

Genus	Caudal basibranchial shape: D = depressed, N = not depressed	Maxillary process of nasal shape: A = broad & heavy, B = moderately broad, C = fairly slender, D = slender	Transpalatine process shape: length/width	Palatine process pre-maxilla: O = absent, sf = slight flange, f = broad flange, —extra process: 0 = absent, number = width	Pneumotricipital fossa: See text page 94	Parasphenoidal rostrum keel: P = prominent, S = slight, R = absent, N = not observed	Tibiotarsus length measured: (mm)
Parmoptila	N	C	3.8	O & sf—0	A&E&F	S&P	20.3
Nigrita	D or N	B&C	3.0–7.3	sf&f—0–0.3	A&F&DO	S	21.8–25.0
Nesocharis	Not	B&C&D	2.8–3.0	sf&f—0–0.3	A&E&F	N	19.0–23.8
Pytilia	D or N	B&C	1.3–1.8	f—0–0.2	A&F	S	22.9–24.3
Mandingoa	N	A&B&C	2.2	f—0.2	A&F	N	22.5
Cryptospiza	N	B&C	2.0–2.6	f—0.05–0.2	A&F	P	25.0–25.9
Pyrenestes	N	A	1.0–1.6	f—0.1–0.2	A&E&F	R	25.0–27.8
Spermophaga	N	A&B	1.2–1.5	f—0.05–0.2	A&E&F&DO	S&R	28.9–29.8
Clytospiza	N	C	1.3	f—0	A&E&DT	S	25.0
Hypargos	D or N	B&C	1.3	f—0	A&E	S	24.1
Euschistospiza	D or N	C&D	1.6	f—0.1	A	N	23.0
Lagonosticta	N	B&C	1.2–1.4	f—0–0.1	A&E&F	S&P	18.2–21.1
Uraeginthus	D or N	C&D	1.2–1.8	f—0–0.2	A&E&F	S&P	21.0–24.8
Estrilda	N	B&C&D	1.3–3.8	f—0–0.2	A&E&F&DO	S	18.9–21.3
Amandava	N	B&C&D	1.2–2.1	f—0–0.1	A&E&F	S&P	17.4–21.6
Ortygospiza	D or N	C&D	1.5–2.4	f—0.2	A&E&F	S&R&P	20.2–20.6
Aegintha	N	C	1.6	f—0.05	A	N	22.4
Emblema	D or N	A&B&C&D	0.8–3.5	f—0–0.2	A&F&DT	S&R	20.7–25.7
Neochmia	D or N	A&C	1.0–1.2	f—0.1–0.2	A&E&F	S&P	20.9–21.9
Poephila	D or N	B&C	0.4–0.9	f—0.1–0.2	A&F&DO	S&P	20.2–22.7
Erythrura	D or N	A&B&C	2.0–4.5	f—0.1–0.2	A&E&F&DO	S&R&P	21.7–24.6
Chloebia	D or N	A&B&C	2.2	f—0.2	E&F	S&P	22.9
Aidemosyne	D	C	1.0	f—0.2	A	P	22.0
Lonchura	D or N	A&B&C&D	0.7–3.0	f—0–0.2	A&E&F	P	19.0–26.7
(Padda)	D	A&B&C	1.6–1.8	f—0–0.1	A&E&F	P	26.2–27.8
Lepidopygia	N	B&C	2.2	f—0.1	A&F	P	18.4
Amadina	N	C	1.1–1.3	f—0.1	A&E&F	P	23.2–24.6

analysis (PCA) ordination for the 127 species (Table 2 and Figs. 1–14). All data were converted to ranks to avoid problems associated with distributions of ratios and lack of normality and to give all variables equal weight. Analyses were performed using PC-ORD (MjM Software 2002).

The specimens and species examined are listed in Appendix 1. The 35 species and one genus not studied are listed in Appendix 2. One taxon (*Estrilda melanotis quartinia*) which was listed as a subspecies by Goodwin (1982) was analyzed separately because it was recognized as a full species by Sibley & Monroe (1990) and Fry & Keith (2004). Eight more taxa split as full species by Sibley & Monroe but lumped as subspecies by Goodwin (1982) were not examined, nor were five more species added by Payne & Sorenson (2004) and Fry & Keith (2004).

Ortygospiza (= *Paludipasser*) *locustella* could not be studied because no skeleton exists in the world's museums (Wood & Schnell 1986). The only one listed by Wood & Schnell could not be found in the Brodkorb collection.

GENERA OF ESTRILDIDAE

The following 15 characters provided the best separation of genera. See Table 1 for a convenient comparison. *Padda* is included for convenience, but it was reduced to a subgenus by Goodwin (1982). They are arranged below

Table 1.—Extended.

Skull length measured: (mm)	Interorbital septum: C = completely ossified, S = small gap, L = large gap, N = not observed	Ectethmoid foramina: D = double, P = pinched, S = single, T = triple. Lateral/medial	Interpalatine process: 0 = absent length/width	Tarsometatarsus shape: length/width	Compression of rostral basibranchial: height/width	Fusion of mediopalatines: % fused	Premaxilla shape: length/width
15.6	C&S&L	D&P 1.1	0.2	9.6	3.0	40	1.9
16.0–18.4	C&S&L	D&P&T 1.3–1.8	0.3–1.7	8.6–9.1	2.2–3.0	27–62	1.4–1.6
13.8–18.4	S	D&P 2.0	0–1.0	9.6–9.9	3.1–3.2	25–100	1.3–1.6
16.2–17.0	C&S	D&P 1.3–3.3	0.2–1.2	8.2–9.4	2.2–2.7	25–58	1.5–1.7
16.6	C	D 2.1	0.2	8.3	3.2	90	1.6
17.5–17.6	C&S&L	D 1.8–1.9	0	10.0–10.2	3.5	29–42	1.6–1.7
18.6–21.0	C	P&S 6.0–14.0	0	8.2–9.4	4.0–4.9	0	1.1–1.2
19.6–21.2	C&S&L	D&P&S&T 3.7–4.5	0.2–0.3	9.4–9.8	3.8–4.2	0–5	1.4–1.5
17.2	C&L	D&P 1.6	0.8	9.2	3.0	66	1.5
17.3	C	D&P 1.3	0.2	8.9	3.6	0	1.4
16.8	N	P&S 1.3	0.8	8.9	2.8	23	1.8
14.5–16.2	C&S&L	P&S 1.0–2.0	0.5–2.5	8.5–9.2	2.1–3.5	10–50	1.3–1.7
15.3–17.0	C&S&L	D&P&S 1.0–1.2	0.2–2.0	9.1–9.8	2.1–3.3	15–75	1.4–1.6
14.0–15.4	C&S&L	D&P 1.6–5.7	0–1.0	9.5–11.1	2.3–3.4	15–100	1.4–1.7
13.0–15.2	C&S&L	D&P&S&T 1.3–1.7	0.4–1.2	8.6–10.1	2.5–2.8	33–58	1.4–1.5
13.8–15.1	C&S&L	D&P&S 1.0–1.7	0.7–1.0	9.0–9.4	2.5–3.0	18–25	1.2–1.4
15.5	C&S	D&P&T 2.3	0	9.8	3.3	86	1.3
15.6–17.4	C&S&L	D&P 1.5–4.0	0.4–2.5	8.7–9.6	3.0–3.4	16–50	1.2–1.7
15.8–16.2	C&S&L	D&T 4.5–7.0	0.4–1.8	8.6–8.7	3.1–3.7	22–61	1.3–1.4
15.0–16.4	C&S&L	D&P 1.9–4.2	0–0.4	8.6–9.8	2.3–3.7	33–94	1.3–1.4
16.6–18.0	C&S&L	D 1.1–2.3	0	7.6–9.3	2.5–4.1	30–88	1.3–1.6
15.9	C&S	D 2.0	0.1	7.8	3.5	60	1.2
15.6	L	D 1.9	0.3	9.1	3.2	65	1.3
13.3–18.8	C&S&L	D&P&S 1.3–10.0	0–1.6	8.1–10.9	2.7–4.6	30–100	1.0–1.7
18.3–19.5	C&S&L	D&P 4.0–6.8	0.8–1.8	8.3–9.0	4.1–4.5	50–60	1.4–1.6
13.8	C	P 2.5	0	9.3	3.3	62	1.2
17.2–18.3	C&L	D&P&T 2.7–3.3	0.6–1.5	7.8	2.9–3.3	10–43	1.3–1.4

in approximately their order of usefulness—that is, the order in which they separate the most genera.

(1) *Shape of caudal basibranchial:* The basilbranchial (= urohyal) was flattened dorsoventrally (depressed) in some species, but slender, not depressed, in others.

(2) *Shape of maxillary process of nasal:* It was only broad and heavy or some broad and heavy and some moderately broad, in *Pyrenestes*, *Spermophaga*, *Erythrura trichroa* (one of the seven species in the genus), and two of the 29 species of *Lonchura*.

(3) *Shape of transpalatine process:* The transpalatine process, at the latero-caudal corner of the palatine bone, was measured as the ratio of its length over its width. It was elongated, 3.3 or more, in *Parmoptila*, two species of *Nigrita*, two species of *Estrilda*, *Emblema oculatum*, and *Erythrura prasina*. It was blunt, under 1.6, in eight genera and parts of eight more.

(4) *Palatine process of premaxilla:* The palatine process of the premaxilla was present as a lateral flange (except in one specimen of *Parmoptila*), but with no suture evident between it and the palatine bone (Tordoff 1954; Bock 1960). Often an additional extension, or process, was present, extending caudally from the lateral edge of the process; sometimes this additional process was as long as 0.3 of the width of the entire lateral flange plus palatine

at that point. The lateral flange was small or slight in *Parmoptila* (absent in one specimen), two species of *Nigrita*, *Nesocharis shelleyi*, and in one specimen of *Clytospiza*; in all other species it was broad. The additional process was lacking in three genera and some specimens or species of 19 more genera.

(5) *Pneumo-tricipital fossa:* The pneumotricipital fossa of the humerus was always double, and usually combined. The various shapes were categorized as they were for Icteridae (Webster 2003): A—Combined dorsal and ventral fossae equally deep, bottom translucent, separation by medial bar incomplete. F—Dorsal and ventral fossae equally deep, but a low, rounded ridge extends distally from the internal tuberosity clear across, separating the fossae. DT—Dorsal and ventral fossae equally deep and translucent-bottomed, but a prominent partition or medial bar extends distally from the internal tuberosity, separating the fossae. E—Dorsal fossa opaque-bottomed, 70–90% as deep as the translucent-bottomed ventral fossa; separation between the fossae a step-down. DO—As in E, but dorsal fossa only 40–60% as deep as the ventral fossa. Only two specimens (of *Clytospiza* and *Emblema guttatum*) were DT.

(6) *Ventral surface of parasphenoidal rostrum:* The base of the parasphenoidal rostrum bore a narrow ventral keel (Sushkin 1927) in some specimens.

(7) *Tibiotarsus length.*

(8) *Skull length:* Measurement was from the caudal end of the external nare. Maximum was 21.2 mm in *Spermophaga ruficapilla*; minimum was 13.0 in *Amandava subflava*.

(9) *Interorbital septum.*

(10) *Ectethmoid foramina:* The ectethmoid (= orbitonasal) foramina were single, pinched, double, or in a few cases triple. However, these divisions were rather erratic within genera or even within species. The relative size of these foramina was fairly consistent within species and genera; it was recorded as size of the lateral foramen over the medial foramen. This was not clear in individuals with a single foramen; if triple foramina were present, the two lateral ones were added together as the numerator.

(11) *Interpalatine process:* The interpalatine process varied from absent to well-developed. It was absent or only a slight bump in five genera and in three species of *Estrilda*, *Poephila bichenovii*, and eight species of *Lonchura*. All other species showed a well-developed process; the maximum of 2.5 was in *Lagonosticta nitidula* and *Emblema oculatum.*

(12) *Tarsometatarsus shape:* The tarsometatarsus varied in stoutness.

(13) *Compression of rostral basibranchial:* The rostral basibranchial (basihyal) was invariably compressed, but the degree of compression (ratio of height to width at the midpoint) varied. This character was omitted from the PCA because so many specimens (all specimens of seven species) lacked the bone.

(14) *Fusion of mediopalatines:* The dorsal walls of the choanal fossa of the paired palatine bones (= mediopalatines) were fused or sutured together in the midline for part (usually) or all of their length, except in *Pyrenestes* and *Hypargos* and a few scattered specimens (no entire species) in other genera. The condition was recorded as the percentage of the length fused (or sutured) of the length where the paired palatines were close to the midline.

(15) *Shape of premaxilla:* The premaxillae varied in their taper, measured as length over width at the caudal end of the external nares. (Of course with the rhamphotheca removed.)

Principal component analysis.—A summary is in Table 2, showing factor loadings. Seven of the best intergeneric chracters are omitted because they are not quantitative (six) or lack complete data (one). On the PCA figures, axis 1 is heavily weighted to long bone ratios between wing and leg—positive correlation to humerus/femur and ulna/tarsometatarsus and negative correlation to tibiotarsus/humerus and tibiotarsus/ulna. Thus species positive on this axis have relatively long wings and short legs; negative values are the opposite. Axis 2 is heavily weighted positively to more slender humerus and broader cranium and negatively to larger lateral ectethmoid foramen and longer postorbital process. Axis 3 is heavily weighted to skull length and tibiotarsus length (measurements of total size); negative values are bigger species.

The following 12 additional characters showed consistency within species, but individually provided only a little in the way of intergeneric variation, or generic characters (all of them were used in the PCA analysis, along with eight of the nine arithmetical characters already discussed): (1) ratio of cranium width–interorbital width, (2) shape of the zygomatic process of the squamosal bone, (3) relative length of the postorbital process, (4) ratio of tibiotarsus length–ulna length, (5) ratio of tibiotarsus length–humerus length, (6) ratio of tibiotarsus length–femur length, (7) ratio of ulna length–femur length, (8) ratio of ulna length–tarsomatatarsus length, (9) ratio of humerus length–femur length, (10) ratio of tarsometarsus length–femur length, (11) ratio of tarsometatarsus length–skull length, (112) ratio of humerus length–width.

Table 2.—Principal component analysis of rank transformed data.

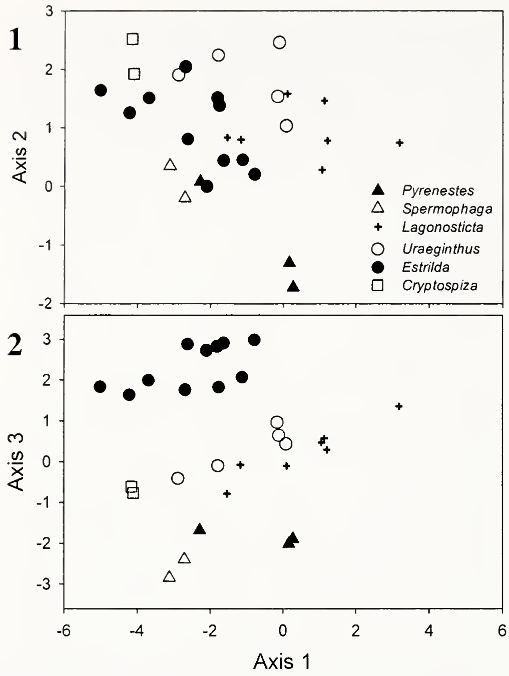
Variable	PC Axis 1	PC Axis 2	PC Axis 3
Skull length	0.071	0.094	−0.554
Premaxilla length/width	0.020	0.293	−0.041
Cranium width/interorbital width	0.061	0.368	0.132
Tibiotarsus length/ulna length	−0.392	−0.040	−0.100
Tibiotarsus length/humerus length	−0.381	−0.127	−0.026
Tibiotarsus length/femur length	−0.234	0.016	0.124
Ulna length/femur length	0.297	0.064	0.186
Humerus length/femur length	0.305	0.193	0.183
Length/width of interpalatine process	0.050	0.080	−0.344
Length/width of transpalatine process	−0.058	0.095	0.158
Length/width of zygomatic process	0.139	−0.245	0.008
Tarsometatarsus length/femur length	−0.265	0.218	0.155
Length/width of tarsometatarsus	−0.337	0.059	0.164
Tarsometatarsus length/skull length	−0.231	0.296	−0.042
Ectethmoid foramina	−0.117	−0.380	−0.083
Ulna length/tarsometatarsus length	0.394	−0.097	0.028
Postorbital process	−0.080	−0.312	−0.130
Mediopalatines joining	−0.083	−0.255	0.213
Tibiotarsus length	0.006	0.107	−0.558
Humerus length/width	−0.108	0.411	−0.027
Eigenvalue	5.668	3.682	2.294
Variance explained	0.283	0.184	0.115
Cumulative variance explained	0.283	0.468	0.582

The PCA analysis (Table 2 and Figs. 1–10) shows these points of generic similarities and differences: *Nesocharis* is very close to *Parmoptila* on both Figs. 1 and 2, but those genera are far from the close cluster of *Nigrita* in both figures. *Cryptospiza*, *Mandingoa*, and *Spermophaga* are the only genera of Estrildini which are separate from all others on all Figs. 1–6. *Estrilda*, *Uraeginthus*, and *Lagonosticta* are separate from one another on Fig. 4, but not on Fig. 3. *Spermophaga* is close to *Pyrenestes*, especially *P. minor*, on both Figs. 3, 4. The twinspots, *Clytospiza*, *Hypargos*, and *Euschistospiza*, but not *Mandingoa*, are close to one another in Figs. 5, 6. *Ortygospiza* is not close to *Amandava* on either Fig. 5 or 6, and the three species of *Amandava* are not well clustered on either figure. *Pytilia* is rather widely split, with *P. melba* far from the other three species in both Figs. 1, 2. *Estrilda* is well clustered, despite the large number of species, in both Figs. 3, 4.

The genera *Aegintha*, *Emblema*, *Neochmia*, and *Poephila* (= *Poephilini*) are all separate from one another in Fig. 8. In Fig. 7, *Aegintha* is within *Emblema* and *Emblema* partly overlaps *Poephila*. *Emblema* is radically split in both figures, with *E. guttatum* and *E. pictum* close to one another and *Poephila* and *E. oculatum* and *E. bellum* near or around *Aegintha*. All five species of *Poephila* are grouped together in both figures. *Aidemosyne* is close to *Neochmia* in both figures.

The genus *Lonchura* is well clustered for such a large group in Fig. 9, and *Aidemosyne* is within it; *Lonchura*, *Padda*, *Erythrura*, *Chloebia*, and *Amadina* are separate from one another, although *Chloebia* is near *Erythrura*. In Fig. 10 of the same genera, *Chloebia* and *Amadina* are separate from the others and each other, but *Aidemosyne*, *Padda* and *Erythrura* overlap *Lonchura*; *Amadina* is outside all the other genera of Estrildidae and not particularly close to any of them on both Figs. 9, 10 and the complete figures (Figs. 11 and 12, where not labeled).

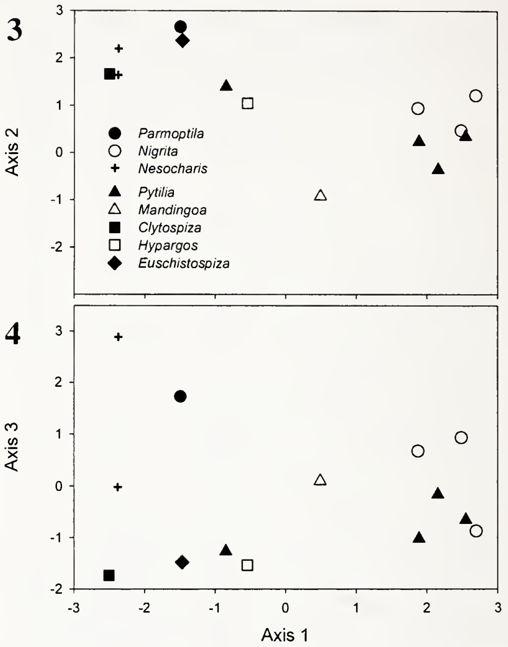
Unused characters.—Twenty-four more characters were tabulated for each specimen, but then abandoned. Of these, nine were too inconsistent within species to be useful: Shape of the lateral margin of the ectethmoid plate, size of the supraotic fenestra, relative lengths



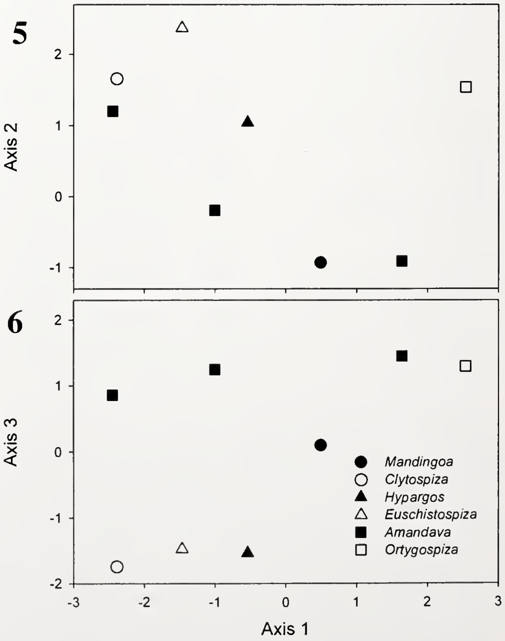
Figures 1, 2.—Results of a principal components analysis (PCA) of 127 species of Estrildidae and Ploceidae, but with all but 6 genera removed. Axis 1 is heavily weighted to long bone ratios between wing and leg. Axis 2 is heavily weighted to certain skull and humerus proportions. Axis 3 is heavily weighted to measurements of total size in mm.

of the metatarsal trochleae, shape of the maxillopalatine bones, shape of the internal (= medial) process of the mandible, presence and nature of the Pocock foramina (Pocock 1966), the degree of the distal bend of the tarsometatarsus, degree of the medial curve of the rostral palatine, and presence and shape of a manubrium-sternum bridge.

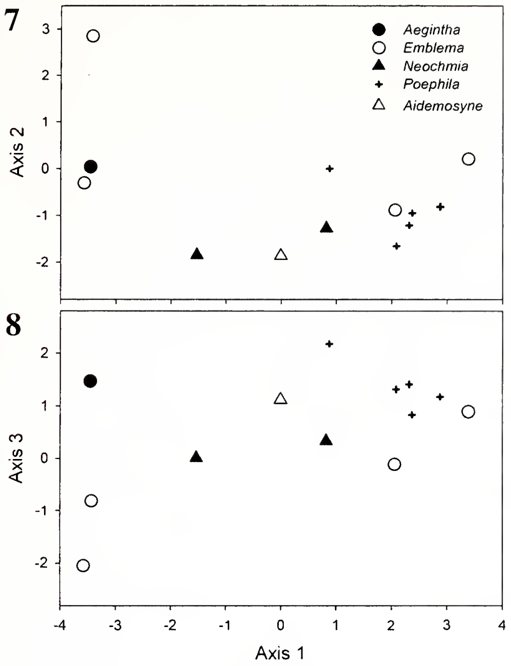
Fifteen characters showed too little variation within the family—were too consistent—to be useful: Degree of ossification of the nasal septum, degree of ossification of the nasal conchs, presence or absence of a horizontal flange of the nasal septum (= floor of the nasal capsule), rostral palatines twisted or not, shape of orbital process of quadrate bone, shape of retroarticular process of mandible, completeness of rostral palate, shape of process 7b of mandible, shape of pseudotemporal process of mandible, presence or absence of a free lacrimal bone, degree of fusion of pterygoid-palatine junction, ratio of ulna length: humerus length, ratio of tibiotarsus length: tar-



Figures 3, 4.—Results of PCA of 134 species of Estrildidae and Ploceidae, but with all but eight genera removed. Axes as in Figures 1 and 2.



Figures 5, 6.—Results of PCA of 134 species of Estrildidae and Ploceidae, but with all but six genera removed. Axes as in Figures 1 and 2.



Figures 7, 8.—Results of PCA of 134 species of Estrildidae and Ploceidae, but with all but five genera removed. Axes as in Figures 1 and 2.

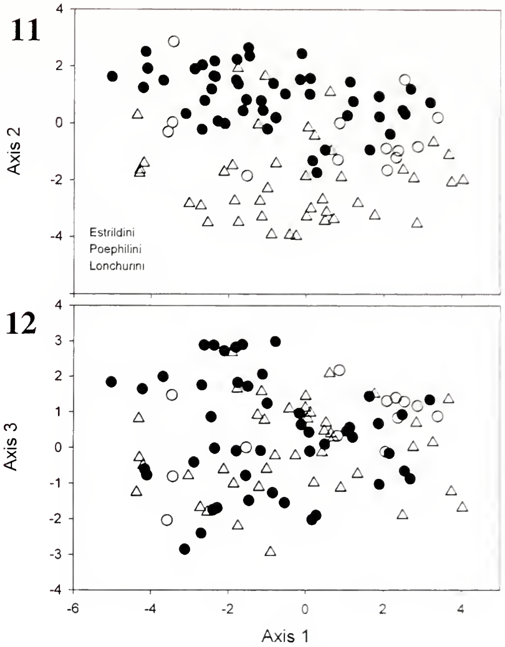
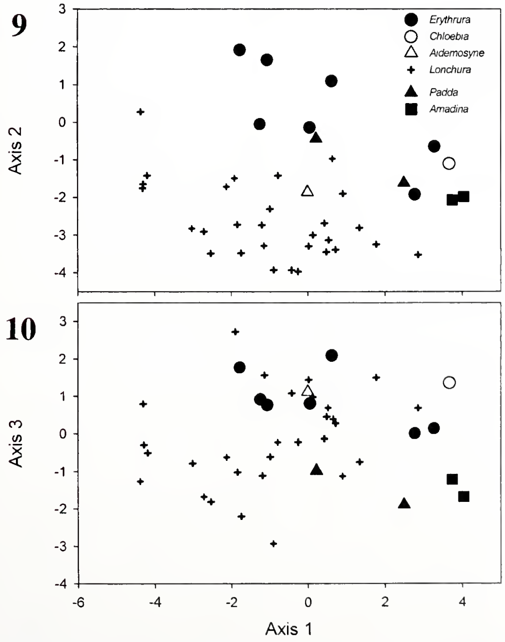
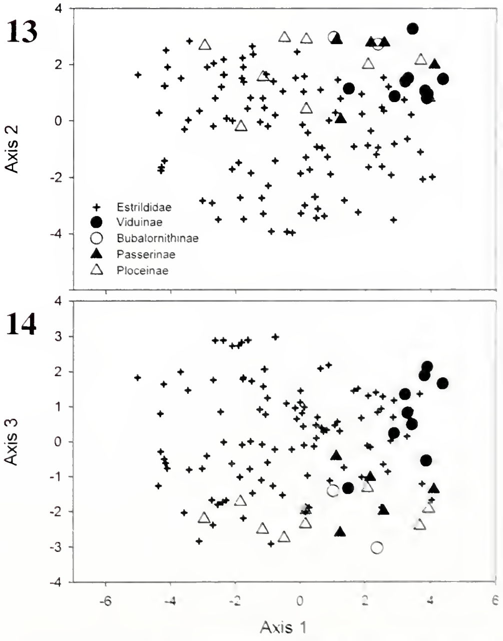


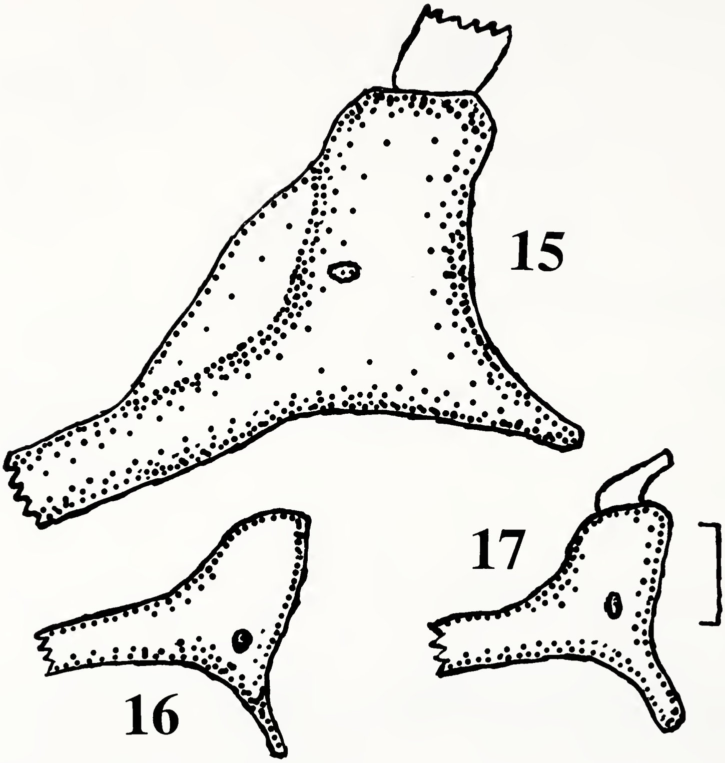
Figure 11, 12.—Results of PCA of 134 species of Estrildidae and Ploceidae, but with the Ploceidae removed, leaving only the 103 species of Estrildidae to compare supposed tribes. Axes as in Figures 1 and 2.



Figures 9, 10.—Results of PCA of 134 species of Estrildidae and Ploceidae, but with all but six genera removed. Axes as in Figures 1 and 2.



Figures 13, 14.—Results of PCA of 134 species of Estrildidae and Ploceidae, complete. Axes as in Figures 1 and 2.



Figures 15–17.—15. *Poephila guttata*, CAS90110; 16. *Passer domesticus*, HA3059; 17. *Vidua fischeri*, MI217526. Right lateral views of the rostral end of the vomer. Rostral to the right, dorsal up in each case. All are drawn with the aid of a camera lucida to the same scale, the 1 mm scale beside 17. In Figs. 15 and 17 the unstippled dorsal projection is a nasal conch fused to the vomer. The smallest species of the three has much the largest vomer.

sometatarsus length, degree of squamosal inflation, shape and size of the rostral end of the vomer.

Boundary of *Lonchura*.—Because there have been so many taxonomists who have split the large genus *Lonchura*, but in a variety of ways, it was analyzed in detail for the 51 tabulated osteological characters (including *Lepidopygia*). For these the maximum and minimum one or two species within the genus were recorded; if three or more tied, it was recorded as no extreme. Altogether, 24 of the 29 examined species were extreme for one or more characters. There were no extremes for 15 characters; there was either no minimum or no maximum extreme for 12 more characters.

Results were: Extreme on nine characters—*Lonchura cantans*. Extreme on seven characters—*L. vana*, *L. monticola*. Extreme on six characters—*L. melaena*. Extreme on four characters—*L. striata*. Extreme on three characters—*L. cucullata*, *L. nevermanni*, *L. teerinki*, *L. pectoralis*. Extreme on two characters—*L. griseicapilla*, *L. bicolor*, *L. fringilloides*, *L. grandis*, *L. hunsteini*, *L. leucosticta*, *L. fuscans*, *L. spectabilis*, *L. flaviprymna*. Extreme on one character—*Lepidopygia nana*, *L. leucogastroides*, *L. tristissima*, *L. malacca*, *L. caniceps*.

The genus *Padda* has been lumped with *Lonchura* by several workers (Delacour 1943; Goodwin 1982; Baptista et al. 1999; Schodde & Mason 1999). When compared with the 29 species of *Lonchura* for the 51 osteological characters, there were these results: both species of *Padda* were beyond the variation in *Lonchura* on three characters. *Padda fuscata* was beyond the variation in *Lonchura* when *Padda oryzivora* was not in three more characters. *Padda oryzivora* was beyond the variation in *Lonchura* when *Padda fuscata* was not in three more characters. The three characters in which both species of *Padda* were outside *Lonchura* were ratio of humerus length to femur length, ratio of ulna length to femur length and caudal basibranchial shape. It is concluded that osteological characters indicate the same as external structural characters—*Padda* may either be retained as a weakly characterized genus or lumped as a subgenus within *Lonchura*.

In the same way, *Euodice*, a subgenus in the Goodwin (1982) classification, was compared with the variation in *Lonchura*. The two species examined, *L. cantans* and *L. griseicapilla*, were not both outside the variation in the rest of *Lonchura* on any character. Similarly, *Spermestes*, another subgenus in the Goodwin (1982) classification, was compared. The three species, *Lonchura cucullata*, *L. bicolor*, and *L. fringilloides* were outside the variation in the rest of *Lonchura* on only one character (shape of the zygomatic process). On two other characters, all but *fringilloides* were outside. As noted above, *Lepidopygia nana* was outside *Lonchura* variation on only one character, length of tibiotarsus. *Lonchura pectoralis* has been split from the large genus as a montypic genus *Heteromunia* by several workers. On osteological characters, then, *Lepidopygia*, *Spermestes* and *Euodice* are not valid genera; and *Heteromunia* is but weakly separate.

Other genera which are weakly characterized on the basis of their skeletons are *Aegintha* (from *Emblema*), *Chloebia* (from *Erythrura*), and *Mandingoa* (from *Pytilia*). Two genera, *Pytilia* and *Emblema*, seem composite osteologically. There is some osteological evidence for the lumping of *Clytospiza*, *Hypargos*, and *Euschistospiza* as Goodwin (1982) suggested.

SUPRAGENERIC TAXA

Tribes.—The Family Estrildidae was divided into three tribes by Delacour (1943) and these were recognized by most subsequent workers. Osteological data don't support a division of the family into three tribes or into two tribes, much less their elevation into subfamilies. In fact, the most distinct groups osteologically (See Table 1) are *Pyrenestes* (with *Spermophaga*) and *Parmoptila* (with *Nesocharis* and *Nigrita*). The PCA (Figs. 11, 12) shows on Fig. 11 about ⅓ of Estrildini overlapping ⅓ of Lonchurini, with both of those tribes mostly overlapping Poephilini. In Fig. 12 there is nearly complete overlap of all three tribes. Different tribal placement of *Amadina* and *Aidemosyne* does not change this point.

Subfamilies.—Osteological data are equivocal as to whether the Viduinae belong in Estrildidae or Ploceidae or in a separate family by themselves. Seven species (21 specimens) of *Vidua* (the whydahs and indigo birds) and two specimens of *Anomalospiza imberbis* (the Cuckoo Finch) were examined, with the results in comparison to the Estrildidae presented in Table 3.

Only the first two characters in Table 3 show consistent differences between Estrildidae and the other two genera. The next five characters show *Anomalospiza* within Estrildid variation, but some or all *Vidua* outside. The last three characters show *Vidua* within Estrildid variation but *Anomalospiza* outside, as noted by Lahti & Payne (2003). Those authors also noted a large median groove in the premaxilla. This observation in *Anomalospiza* is confirmed but not enough Estrildidae were compared with rhamphotheca removed. (Most of the specimens of Estrildidae had been returned to their owners before this comparison.) Not a large enough series of skeletons of any species was examined to speak to their character of delayed pneumatization of the skull.

In summary, *Vidua* and *Anomalospiza* are each more distinct from the 26 genera of estrildids on osteological characters than is any genus within that group except, perhaps, *Pyrenestes*. However, *Vidua* and *Anomalospiza* bear about the same weight of osteological distinction from the other subfamilies of Ploceidae as they do from Estrildidae.

Families.—Sushkin (1927) listed skeletal differences between the Estrildidae (excluding Viduinae) and Ploceidae (Bubalornitinae, Passerinae, and Ploceinae). Findings in this more extensive study are listed in Table 4, with an asterisk (*) marking that mentioned by Sushkin. Only the first character is consistent; the other 11 show some overlap. Presumably the large vomer in Estrildidae functions in seed hulling (Figs. 15–17; *cf* Ziswiler 1979).

Eight more family-differentiating characters mentioned by Sushkin (1927) were found useless. In seven of these Sushkin did not realize the variability within Estrildidae because he

Table 3.—Subfamily characters.

Character	Estrildinae (or Estrildidae)	Viduinae	
		Anomalospiza	*Vidua*
Vomer (Figs. 15–17)	Large, horns broad	Small, horns narrow	Small, horns broad or narrow
Pseudotemporal process of mandible	More ventral	More dorsal	More dorsal
Humerus length: femur length	0.9–1.1	1.1	1.2
Ectethmoid foramina, lateral: dorsal	1.0–14.0	—	0.4–3.8
Tibiotarsus length: ulna length	1.2–1.6	1.3	1.1–1.2
Tibiotarsus length: humerus length	1.4–1.9	1.5	1.3–1.4
Process 7b of mandible	Smaller, sloping except 3% flat-topped	Smaller, sloping	Smaller, sloping except 19% flat-topped and larger in one
Manubrium-sternum bridge	Absent, minute, or small	Very large	Absent or minute
Rostral end of pterygoid	Not expanded except slightly in *Pyrenestes*	Large, heavy, expanded	Not expanded
Caudal end of jugal	Not expanded	Expanded	Not expanded

Table 4.—Family characters. Viduinae excluded. *Noted in Suskin (1927).

Character	Estrilidae	Ploceidae (Bubalornithinae, Passerinae, and Ploceinae)
Vomer (Figs. 15–17)	Large; horns long and broad	Small; horns usually short and narrow
Rostral palatines	Twisted 90°–120°	Not twisted (12 species) or twisted (eight species)
Palatine process of premaxilla (Tordoff 1954, Bock 1960)	Lateral flange, usually prominent	Not a flange, often separated by a suture (12 species) or slight flange (seven species) or prominent flange (one species)
Lateral wall of nasal capsule*	Not ossified	Bone in seven species of four genera
Lateral ectethmoid foramen: medial foramen	1–14, usually high	0.3–9.5, usually low
Interpalatine process, length: width	0–2.5, often absent	0.8–5.2, usually long
Postorbital process of squamosal	0.3–0.7 of way to jugal arch	0.1–0.3 except Euplectes 0.4
Pseudotemporal process of mandible	0.4–1.8, usually below 1.0	0.8–4.7, usually over 1.0
Pneumotricipital fossa of humerus	A, E, F, DO, or DT; 3% DO or DT	A, E, F, DO, DT, or DS; 31% DO or DT or DS
Tibiotarsus length: tarsometatarsus length	1.3–1.7	1.3–1.5
Tibiotarsus length	17.4–29.8 mm	23.7–46.0 mm (eight of 20 species over 29.8)
Skull length	13.0–21.2 mm	17.3–27.4 mm (10 of 20 species over 21.2)

lacked specimens of *Parmoptila*, *Nigrita*, *Nesocharis*, and several other genera. These characters were: position of the club of the maxillopalatine, medial curvature of the rostral palatine, length of the interpalatine space, position of the palatal crests, shape of the rostral end of the vomer in ventral view, nature of the pterygoid-palatine joint, and size or presence of an interorbital fontanel. One character mentioned by Sushkin, the constriction of the rostral palatine in its caudal region in a direct ventral view is better expressed as the twist of the bone at that point, as described by Tordoff (1954) and above. The actual relative width of the palatine at that point varies little from species to species.

Schodde & Mason (1999) included five skeletal characters in their characterization of the family Estrildidae. Of these, three are evidently the same as those listed above, although the terminology is different. One was noted, but not tabulated—"vestigially toothed mandibular angle." One, "vestigial maxillopalatine process," was too variable within Estrildidae, even within species, to be useful.

The PCA figures show a broad overlap between Estrildidae and Ploceidae (four subfamilies, with *Anomalospiza* in Viduinae) in Fig. 14 and a lesser overlap between Estrildidae and Ploceidae of three of these subfamilies (Passerinae, Viduinae, and Bubalornithinae) in Fig. 13.

In five more tabulated characters there was some difference in a few species between Estrildidae and Ploceidae, but there were large areas of overlap: size of the retroarticular process of the mandible, shape of the caudal basibranchial, presence and size of a manubrium-sternum bridge, ratio of tarsometatarsus length to skull length, and ratio of humerus length to femur length.

DISCUSSION

Traylor (1968) put *Pholidornis rushiae* (Cassin) in Estrildidae as a genus *incertae sedis*. Apparently there is no complete skeleton in the world's museums (Wood & Schnell 1986), but the lone skull in the British Museum was examined. It is certainly not an estrildid; it exceeds the variation in that family on 11 of the 26 tabulated osteologic characters of the skull. The premaxilla is too long and slender, there is no palatine process of the premaxilla, there is no bone in the nasal septum, the vomer bears no horns, and the rostral palatines aren't twisted, etc. However, with neither a hyoid or a humerus a more specific family identification is unwise. Sefc et al. (2003) placed *Pholidornis* in the Sylvioidea, close to Cisticolidae.

The small, slender, rostral tongue bone figured by Ziswiler (1979) and called hypentoglossum in Estrildidae was not clear in most dried skeletons. It was clear, however, in a few specimens of four different genera. No doubt its presence or absence must be ascertained in fresh or spirit-preserved material for an analysis.

Schodde & Mason (1999) revised the genera of Australian Estrildidae. They put *Aegintha* into *Neochmia*, segregated *Emblema bellum*, *E. oculatum*, and *E. guttatum* into *Stagonopleura*, and left *E. pictum* as the only species in *Emblema*. Also they moved *Aidemosyne* into *Neochima* and split *Poephila* into *Taeniopygia* with *guttata* and *bichenovii*, leaving *Poephila* including only *P. personata*, *P. acuticauda*, and *P. cincta*. *Chloebia* they lumped into *Erythrura*. Of these changes, osteologic characters do not agree with their disposition of *Aegintha*—rather it should be put in *Stagonopleura*. *Emblema guttatum* should be left in *Emblema*, which would then require changing the name *Stagonopleura* to *Zonaeginthus*. The placement of *Aidemosyne* in *Neochmia* agrees with osteology. The split of *Poephila* is quite unnecessary—the five species form a close group on osteologic evidence. The placement of *Chloebia within Erythrara* is equivocal on osteologic characters. Moving of the genus *Amadina* to a position within the almost strictly African Estrildini as advocated by Walters (1957). Goodwin (1982), Baptista et al. (1999), and Fry & Keith (2004) is neither supported nor denied by osteologic data.

Evolutionary history within Estrildidae has been studied by several workers. Delacour (1943) and Steiner (1960) nominated *Clytospiza* as most like an ancestral form. Mayr (1968) was not explicit, but seemed inclined toward either *Clytospiza* or *Parmoptila* as nearest an ancestral form. Goodwin (1982) suggested that *Amandava* was probably nearest to an ancestral estrildid. Of the several molecular studies (Kakizawa & Watada 1985; Christidis 1987; Baptista et al. 1999; Sorenson & Payne 2001, 2002; Payne & Sorenson

2003; Sorenson et al. 2004; Van der Meij et al. 2005) only Sorenson & Payne studied nearly all of the genera and a majority of the species. All of these workers found an ancient divergence between the African Estrildini and the primarily Australasian Lonchurini plus Poephelini. However, Kakizawa & Watada found Australasian *Erythrura* and *Chloebia* within the African group, and Christidis found African *Amadina* within the Australasian group, near *Lonchura*. Sorenson & Payne (2001, 2002) found *Ortygospiza locustella* (= *Paludipasser locustella*) distinct and representing a group ancestral to all other estrildids. (That species was examined by none of the other molecular workers nor was a skeleton available for this study.)

The recent treatment of Estrildidae by Sorenson & Payne (2001, 2002), Payne & Sorenson (2003), and Sorenson et al. (2004) should be compared with this work. Actually, there are only these distinct differences: (1) There are no skeletal data on *Paludipasser* (= *Ortygospiza*) *locustella* to compare. (2) They recognize 13 more genera than this work, including a split of *Lonchura* into six genera; most of these were subgenera in the Goodwin (1982) scheme.

Relationships of *Vidua* and *Anomalospiza* to Estrildidae have been variously hypothesized. Most systematists who have studied the question—Chapin (1917, 1929, 1954), Sushkin (1927), Delacour (1943), Tordoff (1954), Wolters (1957, 1960), Friedman (1960, 1962), Bentz (1979), Sibley & Ahlquist (1990), Lahti & Payne (2003), and Fry & Keith (2004)—placed the whydahs closer to their hosts, the waxbills, than to any other systematic group. On the other hand, Beecher (1953), Steiner (1960), Nicolai (1964), Ziswiler (1967), Mayr (1968), Mayr et al. (1968), and Goodwin (1982) placed the whydahs closer to one or another ploceid group than to the waxbills. Recent studies of *Anomalospiza* by Sorenson & Payne (2001) and Lahti & Payne (2003) placed that genus close to *Vidua*. Cramp & Perrins (1994) and Fry & Keith (2004) separated Passeridae as a separate family from Ploceidae.

The family Estrildidae is a relatively homogenous group on osteologic characters, contrasting with Emberizinae (Webster & Webster 1999) and Icteridae (Webster 2003) in this respect. No taxonomic changes in the arrangement in Goodwin (1982) above the species level are recommended except the deletion of *Pholidornis*, the dropping of tribes, and the lumping of *Lepidopygia* with *Lonchura*. Probably, also, the genera *Clytospiza* and *Euschistospiza* should be united with *Hypargos* following the suggestion by Goodwin (1982). Probably the genus *Zonaeginthus* should be recognized to include *Emblema bellum*, *Emblema oculatum*, and *Aegintha temporalis*. Probably *Aidemosyne modesta* should be transferred to *Neochmia*. Recognition of the genera *Padda* and *Heteromunia* (splits from *Lonchura* not recognized by Goodwin (1982) are equivocal, as is the lumping of *Chloebia* with *Erythrura*. Whether the subfamily Viduinae should be transferred from Ploceidae to Estrildidae or segregated as a separate family is not clarified by osteology.

ACKNOWLEDGMENTS

In 2000, shortly before his death, Luis Baptista requested and encouraged me to study the skeletons of Estrildidae. This paper is the result of that encouragement, but without his help. I thank the curators of these museums for allowing me to study specimens under their care: American Museum of Natural History, California Academy of Sciences, Carnegie Museum of Natural History, Field Museum of Natural History, University of Kansas Museum of Natural History, Los Angeles County Museum, Louisiana State University Museum of Science, University of Michigan Museum of Zoology, Royal Ontario Museum, The Natural History Museum of the United Kingdom, United States National Museum, Peabody Museum of Natural History of Yale University. I thank David L. Auth for measuring three skeletons at the Florida Museum of Natural History. Richard L. Zusi kindly explained some old, obscure skeletal terminology for me. Jackson R. Webster performed the statistical analysis. The manuscript was helpfully reviewed by Michael A. Patten and three anonymous reviewers.

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Appendix 1.

Specimens examined. Museum designations: AM, American Museum of Natural History. CAS, California Academy of Sciences. CM, Carnegie Museum of Natural History. FL, Florida State Museum. FM, Field Museum of Natural History. HA, Hanover College. KS, University of Kansas Museum of Natural History. LAC, Los Angeles County Museum. LSU, Louisiana State Museum of Science. MI, University of Michigan Museum of Zoology. RO, Royal Ontario Museum. BM, The Natural History of Museum of the United Kingdom. US, United States National Museum. YP, Peabody Museum of Natural History of Yale University.

Estrildidae:

Parmoptila woodhousei, 5 FM385327, US292451, US292452, BM S/1980. 6.2, AM24935
Nigrita fusconota, 4 FM313270, FM3835328, US322542, US292481
Nigrita bicolor, 3 US 347578, US292479, US292480
Nigrita canicapila, 5 FM356422, KS70888, US291136, US292478, YP9410
Nesocharis shelleyi, 2 US318625, US318626
Nesocharis capistrata, 1 MI201774
Pytilia phoenicoptera, 3 AM12715, AM12829, BM S/1966. 39.20
Pytilia hypogrammica, 3 AM12268, AM14084, AM16495

Appendix 1.

Continued.

Pytilia afra, 3 AM12346, AM12660, AM12347
Pytilia melba, 5 US430316, US429100, US558781, LAC89770, LAC89768
Mandingoa nititula, 6 AM13700, AM13698, AM13701, MI1214380, MI207779, BM1981.82.2
Cryptospiza reichenovii, 2 BM S/1992.27.1, S/992.27.2
Cryptospiza salvadorii, 5 FM356455, FM356459, FM356458, KS70941, KS70942
Pyrenestes sanguineus, 4 AM13696, AM13759, AM13697, BM S/1993.38:1
Pyrenestes ostrinus, 4 AM12686, AM17105, AM17104, MI232532
Pyrenestes minor, 2 MI214379, MI214378
Spermophaga haematina, 6 US347593, US322435, US322434, CAS71723, MI2221317, MI1221316
Spermophaga ruficapilla, 4 MI223525, MI208342, US499894, YP13765
Clytospiza monteiri, 4 MI201775, MI201776, MI232533, AM24947
Hypargos niveoguttatus, 4 CAS71724, AM11819, KS80654, CAS71724
Euschistospiza dybowskii, 3 AM14260, AM14261, AM14263
Lagonostica rara, 3 CAS71727, CAS71726, CAS71727

Appendix 1.

Continued.

Lagonostica rufopicta, 4 AM14304, AM14046, MI221300, MI221308
Lagonostica nitidula, 2 MI203301, BM S/958.19.1
Lagonosticta senegala, 4 US430652, US502062, CAS83508, CAS71730
Lagonostica rubricata, 6 CAS84857, AM14082, AM13205, AM13204, BMS/1986.75.26, BM S/5.24
Lagonosticta rhodopareia, 3 US430676, US430807, BM S/1982.77.3
Lagonosticta larvata, 3 AM14135, MI221311, MI221312
Uraeginthus angolensis, 5 US558782, US431594, US430001, BM S/1982.136.5, BM S/982.136.2.
Uraeginthus bengalus, 5 CAS71738, CAS85089, LAC89787, LAC89790, YP9272
Uraeginthus cyanocephalus, 4 AM8759, AM8809, AM8767, CAS90061
Uraeginthus granatina, 6 CAS71734, MI222633, MI220363, MI233565, BM S/1991.1.27, BMS/991.1.28
Uraeginthus ianthinogaster, 4 AM11915, AM‘12086, AM12087, BM S/1987.23.15
Estrilda caerulescens, 4 CAS42861, US347286, US557890, CAS42861
Estrilda perreini, 1 BM S/1962.18.1
Estrilda melanotis, 3 MI218669, CAS90031, CAS90030
Estrilda melanotis quartinia, 1 MI218670
Estrilda paludicola, 3 FM362222, FM362221 FM362220
Estrilda melpoda, 4 CAS71735, MI223530, MI223531, BM 1891.7.20.188
Estrilda rhodopyga, 3 AM11812, AM11832, CAS90074
Estrilda troglodytes, 5 AM11829, AM11818, AM12173, BM S/1966.39.10, BM S/1966.39.8
Estrilda astrild, 5 US490778, US490874, US490779, BM S/1990.3.3, BM S/1990.3.2
Estrilda nonnula, 3 LAC89798, LAC90692, LAC89800
Estrilda atricapilla, 3 FM385352, FM358204, FM313281
Estrilda erythronota, 4 CAS71422, MI222628, MI233264, CAS90073
Amandava amandava, 6 US556164, US5556156, FM96103, CAS90068, CAS90026, BM S/1962.12.2
Amandava formosa, 3 LAC90694, FM106437, BM S/1986.75.38
Amandava subflava, 5 US322525, US432034, US322505, KS31150, CAS90027

Appendix 1.

Continued.

Ortygospiza atricollis, 5 AM1410, AM14141, AM14138, BM S/1998.48.73, CAS90105
Ortygospiza species, 2 BM S/1967.5.1, FL31619 (incomplete data, measured by Auth)
Aegintha temporalis, 5 MI204457, MI205437, MI205436, FM105467, FM105492
Emblema pictum, 6 CAS57594, CAS60370, AM12831, AM11814, BM S/1954.7.1, CAS60371
Emblema bellum, 3 RO186380, RO136166, RO136378
Emblema oculatum, 2 FM104083, FL31621 (incomplete data, measured by Auth)
Emblema guttatum, 6 CAS84574, CAS57637, AM10737, AM10331, BM1867.7.8.16, BM1865.5.20.13
Neochmia phaeton, 4 CAS60372, AM12964, AM12966, BM S/1998.48.52
Neochmia ruficauda, 4 CAS83891, CAS71740, BM S/1984.28.1, CAS71738
Poephila guttata, 8 MI220494, MI205109, MI219070, KS83369, KS83322, KS80636, CAS90110, CAS90058
Poephila bichenovii, 4 US620269, US343821, US620270, BM S/1983.129.1
Poephila personata, 5 MI205599, MI205598, MI119233, FM104058, FM96083
Poephila acuticauda, 5 US345241, US354284, US344878, BM S/1984.28.10, BM S/1984.28.11
Poephila cincta, 5 CAS43603, MI119234, FM96152, FM105362, KS80879
Erythrura hyperthra, 4 CAS85132, AM11846, AM11844, BM S/1984.27.1
Erythrura prasina, 6 US344594, US344497, US614130, CAS71753, BM S/1989.2543, BM S/1987.23.20
Erythrura viridifacies, 3 BM S/1982.104.1, BM S/1983.133.1, BM S/1984.30.1
Erythrura trichroa, 5 MI210799, MI209458, MI210798, FM104454, FM104172
Erythrura psittacea, 5 CAS48970, MI221643, MI220930, KS80964, KS80963
Erythrura tricolor, 2 CAS90129, CAS No #
Erythrura pealii, 4 CAS42707, CAS90118, BM S/1993.16.4, FL31650 (incomplete data, measured by Auth)
Chloebia gouldiae, 7 US321161, US501540, CAS71477, CAS84820, BM S/1954.1.1, BM S/1981.91.2, CAS60949
Aidemosyne modesta, 3 CAS57865, MI205612, MI205613
Lepidopygia nana, 2 MI208433, BM1897.5.10.48

Appendix 1.

Continued.

Lonchura cantans, 3 AM12913, AM11994, AM12263
Lonchura griseicapilla, 5 CAS85726, FM362202, FM362201, KS70556, KS70524
Lonchura cucullata, 3 US556170, US556174, US556076
Lonchura bicolor, 3 US347586, US347587, US347585
Lonchura fringilloides, 3 LSU160452, LSU111948, AM16453
Lonchura striata, 5 CAS84020, CAS85461, FM315110, FM104099, CAS71540
Lonchura leucogastroides, 3 CAS85105, CAS85712, BM S/1985.32.1
Lonchura fuscans, 2 KS41000, KS41118
Lonchura molucca, 5 US557491, US557484, US557485, US557489, US557483
Lonchura punctulata, 4 CAS85727, MI235135, MI207365, LAC89840
Lonchura leucogastra, 3 MI206402, MI206399, MI206401
Lonchura tristissima, 5 MI21585, LSU101032, YP9000, YP8999, YP8998
Lonchura leucosticta, 3 AM12832, AM11796, AM12834
Lonchura quinticolor, 4 CAS85108, CAS90081, CAS90050, CAS90049
Lonchura malacca, 4 KS31144, KS41357, CAS84904, CAS No #
Lonchura maja, 4 CAS85109, CAS85728, US345468, US344591
Lonchura grandis, 3 LSU101033, YP8977, YP8978
Lonchura vana, 1 KS41113
Lonchura caniceps, 4 LAC89850, LAC89849, FM290944, YP6190
Lonchura nevermanni, 3 AM12948, AM12657, AM11835
Lonchura spectabilis, 7 CAS85111, KS81180, US489252, US289250, YP8987, YP8991, YP8985
Lonchura hunsteini, 3 LSU85929, LSU86921, LSU86928
Lonchura flaviprymna, 3 FM105853, FM105901, FM314884
Lonchura castaneothorax, 4 CAS85309, FM343031, FM96143, CAS90080
Lonchura teerinki, 2 CAS90147, CAS90159
Lonchura monticola, 1 AM5820
Lonchura melaena, 1 BM S/1961.11.48
Lonchura pectoralis, 5 AM12906, MI214327, KS83207, CM7240, CM7242
(Padda) fuscata, 3 CAS85729, CAS90085, CAS90059
(Padda) oryzivora, 4 CAS58654, CAS71539, CAS85747, CAS85314

Appendix 1.

Continued.

Amadina erythrocephala, 4 US429108, US429109, US429107, BM S/2003.4.3
Amadina fasciata, 8 CAS85625, CAS85536, AM11963, AM11965, LAC89852, LAC102979, YP102898, YP103284

Hyliidae:

Pholidornis rushiae, 1 BM 1930.12.3.11

Ploceidae, Viduinae:

Vidua chalybeata, 3 MI222621, MI218102, MI222620
Vidua funerea, 2 CM9573, CM9571
Vidua funerea purpurascens, 2 MI223739, MI223738
Vidua fischeri, 3 BM S/1993.30.1, MI217526, MI212960
Vidua regia, 2 MI204760, MI222615
Vidua macroura, 2 MI212961, MI136012
Vidua paradisaea, 5 MI222619, MI224501, RON149481, RON126721, BM 1982.54.1
Vidua orientalis, 2 CAR9570, CAR9569
Anomalospiza imberbis, 2 MI217511, MI219072

Ploceidae, Bubalornithinae:

Bubalornis albirostris, 2 RON156913, US430787
Dinemiellia dinemelli, 2 KS70745, KS70744

Ploceidae, Passerinae:

Plocepasser mahali, 1 KS70632
Pseudonigrita arnaudi, 2 CM7266, CM7267
Passer domesticus, 9 HA3056, HA3059, HA3205, records lost of 6
Passer montanus, 1 MI119071
Petronia xanthocollis, 2 KS70447, KS70773
Sporopipes frontalis, 4 KS70628, YP13245, YP13250, US490719

Ploceidae, Ploceinae:

Amblyospiza albifrons, 3 CM789, CM785, US322509
Ploceus ocularis, 2 RO114496, RO114466
Ploceus melanogaster, 1 KS71003
Ploceus cucullatus, 5 YP9413, YP7500, MI221231, MI221191, MI221216
Ploceus philippinus, 1 YP9828
Malimbus rubricollis, 2 YP9412, YP9411
Malimbus malimbicus, 1 US291132
Malimbus rubriceps, 2 RO114571, RO114577
Quelea quelea, 7 RO12076, RO120766, MI219934, MI219943, MI219949, MI219953, MI219958
Foudia madagascariensis, 1 US432205
Euplectes orix, 2 CM1575, CM16514
Euplectes ardens, 2 KS71020, KS71019

Appendix 2.

Species of Estrildidae whose skeletons were not studied. An asterisk (*) means that no skeleton exists in the world's museums, according to Wood & Schnell (1986). Thirteen species recognized by various recent workers but not by Goodwin (1982) are included.

Parmoptila rubrifrons
*Nigrita luteifrons**
*Nesocharis ansorgei**
Pytilia lineata
Cryptospiza jacksoni
*Cryptospiza shelleyi**
Spermophaga poliogenys
Hypargos margaritatus
Euschistospiza cinereovinacea
*Lagonsticta landanae**
Lagonosticta virata
Lagonosticta vinacea
Estrilda thomensis
Estrilda rufibarba
*Estrilda nigriloris**
*Estrilda charmosyna**
Estrilda polioparia
Estrilda kandti
*Ortygospiza gabonensis**
*Ortygospiza locustella**
*Oreostruthus fuliginosus**
*Erythrura coloria**
Erythrura papuana
Erythrura regia
*Erythrura kleinschmidti**
Erythrura cyaneovirens
Lonchura malabarica
Lonchura nigriceps
Lonchura kelaarti
Lonchura ferruginosa
*Lonchura pallida**
Lonchura forbesi
Lonchura nigerrima
Lonchura stygia
*Lonchura montana**

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SHORT COMMUNICATION

POINT-CENTERED-QUARTER ANALYSIS OF THE UPLAND FOREST AT YUHAS WOODS IN RANDOLPH COUNTY, INDIANA

Holly Baltzer, **Donald Ruch**, **Benjamin Hess** and **Byron Torke**: Department of Biology, Ball State University, Muncie, Indiana 47306-0440 USA

The Frank and Phyllis Yuhas Woods is one of the most botanically rich and diverse natural areas in east-central Indiana. It is a 33.6 ha tract with approximately 30 ha of woodland located in the southwest region of Randolph County, Indiana. It is owed by The Red Tail Nature Conservancy. Yuhas Woods lies in the Tipton Till Plain section of the Central Till Plain Natural Region. This region of Indiana was comprised of beech-maple forests with scattered sections of oak-hickory forests during presettlement times (Homoya et al. 1985). It is now mostly agricultural land with scattered woodlots.

The composition of tree species in a forest indicates much about its overall structure and habitat. In August of 2005, a systematic point-centered-quarter (PCQ) technique was used to provide basic statistics, e.g., frequency, basal area, and density, of the tree composition of the upland forest at Yuhas Woods. From these measures relative frequency (RFREQ, the percent frequency of one species per ha compared to all species), relative basal area (RBA, the percent basal area for one species compared to the total basal area for all species), and relative density (RDEN, the percent density of one species compared to all species per ha) were calculated and used to determine importance values (IV, the sum of RDEN, RBA and RFREQ) and relative importance values (RIV, the average of RDEN, RBA, and RFREQ expressed as a percent) for all tree species recorded (Cottam and Curtis 1956).

Only trees with a DBH (diameter at breast height) ≥ 10 cm were sampled. The DBH (to the nearest 0.1 cm), the distance from the middle of the stem to the point (to the nearest 0.1 m), and the species were recorded. These data provided the basis to place Yuhas Woods into a classification system devised by Lindsey et. al. (1965). This study is part of a larger project examining the floral compositions of woody and herbaceous vegetation at Yuhas Woods. Nomenclature follows Gleason & Cronquist (1991).

A total of 29 species with a DBH ≥ 10 cm was documented. The results from the top six most important species can be seen in Table 1. *Acer saccharum* ranked highest in relative importance due primarily to its high frequency of smaller-sized trees. *Quercus alba* and *Ulmus rubra* were the next most important and the only other species with relative importance values above 9.0. The high RIV of *Q. alba* was due principally to one very large stem (DBH = 77.7 cm), since its frequency was much less than *A. saccharum*. Similar to *A. saccharum*, the RIV of *U. rubra* was due to a high frequency of small stems. *Carya ovata* ranked fourth and was followed by a steady decline in RIV by *Prunus serotina* and *Carya cordiformis*. No other species in the upland woods had a RIV above 5.0. For later classification purposes, the RIV for all *Quercus* species (e.g., *Q. alba*, *Q. muhlenbergii* Engelm., *Q. palustris* Muenchh., *Q. rubra*, and *Q. velutina* Lam.) was calculated at 19.1, for all *Carya* species (e.g., *C. cordiformis*, *C. glabra* (Miller) Sweet, and *C. ovata*) at 14.5, and the RIV of *Fagus grandifolia* Ehrh. was 0.8.

According to Lindsey et al. (1965), for a wooded area to be classified as Oak-Hickory the total IV of *Quercus* spp. and *Carya* spp. must be double that of *Acer saccharum* plus *Fagus grandifolia*. Respectively, their IVs are 101.6 and 79.0. These IVs do not meet the requirements set down by Lindsey et. al. (1965) for Yuhas Woods to be classified as Oak-Hickory; thus, it is best classified as a Mixed Woods. However, *Quercus* spp. and *Carya* spp. made up 33.6% of the overall RIV, overtopping the combined RIV of *A. saccharum* and *F. grandifolia* by almost 10.0%. Despite the data indicating a comparative IV not high enough to classify the woods as Oak-Hickory, the data do indicate that the oaks and hickories are of major importance.

Yuhas Woods may have once been classified as an Oak-Hickory forest. Yuhas has been selectively logged throughout its recent history, especially for oaks (Gibbons pers. commun.; Perkins pers. commun.). Selective harvesting of oak forests does not always promote oak re-establishment, and it may hasten the conversion of the land to another type of

Table 1.—Data for the upland forest of Yuhas Woods. Species are listed by the relative importance values. Density (DEN) is the number of stems per hectare. Relative density (RDEN) is the number of individuals of a species relative to the total number of trees expressed as a percent. Basal area (BA) is the meters squared per hectare of each species. Relative basal area (RBA) is the total basal area of a species relative to the total basal area of all species expressed as a percent. Frequency (FREQ) is the proportion of plots in which a species occurred relative to the total number of plots. Relative frequency (RFREQ) is the frequency of each species relative to all species expressed as a percent. Importance value (IV) is the sum of RDEN, RBA, and RFREQ. Relative importance value (RIV) is the average of RDEN, RBA, and RFREQ expressed as a percent.

Species	DEN	RDEN	BA	RBA	FREQ	RFREQ	IV	RIV
Acer saccharum Marsh.	137.5	31.7	6.3	21.1	0.7	23.7	76.5	25.5
Quercus alba L.	39.3	9.0	5.4	18.2	0.3	10.1	37.4	12.5
Ulmus rubra Muhl.	42.4	9.8	2.0	6.9	0.3	11.2	27.8	9.3
Carya ovata (Mill.) Koch	32.0	7.4	1.7	5.9	0.2	7.8	21.0	7.0
Prunus serotina Ehrh.	32.0	7.4	0.9	3.2	0.2	7.1	17.6	5.9
Carya cordiformis (Wang.) Koch	25.8	6.0	1.7	5.9	0.2	5.4	17.2	5.7

woods (Lorimer 1983). Also, it has been demonstrated that *A. saccharum* outcompetes *Quercus* spp. in small canopy gaps created by selective logging (Parker & Sherwood 1986). Another factor is the suppression of fire in this region since European settlement that may have kept many forests from reaching a climax community (Abrams 1992; McClain 1993). Oak forests are considered to be an early-to-mid stage of succession, with the next stage composed of more shade-tolerant but fire-intolerant trees such as *Acer saccharum* (Abram 1992). These factors make it probable that the lack of oak trees in Yuhas Woods is due to the past logging and fire suppression and, had more oaks been found, the total IV for *Quercus* spp. and *Carya* spp. would have doubled the total for *A. saccharum* and *F. grandifolia*.

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MINUTES OF THE MEETINGS OF THE INDIANA ACADEMY OF SCIENCE 2006

MEETING OF THE EXECUTIVE COMMITTEE

Ball State University
21 April 2006

The Executive Committee met briefly before the Council meeting. Those attending were Frank Guthrie, Ed Frazier, Clare Chatot, John Schutt, Nelson Shaffer and Jim Berry.

The minutes of the previous meeting were distributed and approved.

President Clare Chatot, Gary Dodson, Linda Airy, and Jim Bandoli were asked to review IAS statements on the teaching of evolution. Clare Chatot wanted the statement to be in the newsletter and on the web site. The new version was approved to be taken to the Council.

President Chatot mentioned that the Cell Biology and Microbiology section and the Molecular Biology section may merge into a single section as part of Uwe Hansen's technical initiative.

A request was made to add the section to which members belong in the yearbook. Nelson will add the section designation.

The meeting was adjourned at 2:30 PM.

MEETING OF THE COUNCIL

Ball State University
21 April 2006

President Clare Chatot called the meeting to order at 2:37 PM. A list of agenda items was distributed, and the minutes of the previous meeting were approved unanimously.

Treasurer Ed Frazier explained the financial accounts and noted that the figures are incomplete at this early date. We have not yet received funds from the state for the *Proceedings*. Publications have generated some money, and a small amount of grant money was returned.

There was no activity in the Indiana Biological Survey Account Welch Fund. The $400 interest usually goes to a grant usually for a biologist. The Past President fund (funded by Bill Lovell) prepaid $5,130 for last year's meeting. There were no applicants for the grant last year, and we still have $500 in the account.

The Executive Director reported on membership and status of yearbook.

Jim Berry reported that the most recent issue of *Proceedings* included a biography of a valued and esteemed member of the Academy: Dr. Dan Webster of Hanover College. The next biography will feature Dr. Marion Jackson of Indiana State University. The Fall issue of the Proceedings will include the papers from the Wabash River Symposium.

Don Ruch reported that the newsletter is in good shape. He sent a note to section chairs requesting important items to include in the newsletter or for a feature article.

President-Elect John Schutt will run the student presentation competition.

President Clare Chatot wants to revise the resolution about teaching evolution in public schools. She will continue the technical initiative, with modest support to sections of the Academy to bring in a good speaker or other attraction for the meeting. She can do two or three of these initiatives at $200–$300. Anthropology, Science Education, and Math used this program last year. Dr. Chatot called for section proposals. Don Ruch will invite Robert Mulenbrach. Action on the resolution on evolution was deferred until later.

Frank Guthrie reported for the Academy Foundation that changing the account to Merrill Lynch has worked well. Stanley Burden and Wendell McBurney are co-trustees. The committee tries to balance income (*i.e.*, bonds with growth stocks, mutual funds, etc.). We should have enough income for the Foundation to pay for publications, the *Proceedings*, and other needs while operating within the confines of the requirements of the Wright Fund.

Don Ruch has written grants for several years, and has received a total amount of

$60,000. This year he will need someone else to write a proposal for high school funds.

David Daniell reported that the 2007 meeting will be held at the University of Indianapolis. John Langdon is the contact person. There are no dates set yet—possibly the end of October.

Local Arrangements: For the Spring 2006 meeting, dinner will be at the Alumni Center near the football stadium. The Geology field trip will be to Brookville, and the Botany field trip will be to Ginn Woods. For the Fall meeting, there will be a buffet dinner at the Student Union. Members must park at the stadium and ride shuttle buses. There will be a planetarium show, tree identification, and the Jackson Tree book (tentative). Registration will be $30–$35—a bit higher this year.

Nominations and Elections: Mike Foos reported that nomination forms have been revised to require only two signatures. Forms must be submitted by May 1. We may need a new secretary, and we will need a candidate for the Academy Foundation. Also, the Research and Grants Committee needs a member from the physical sciences. Jeff Hughes will step down as chair.

Publications: Nelson Shaffer related a phone conversation from Bill McKnight indicating that he would like to step-down from the Publications Committee chair within a few years.

Resolutions: President Chatot wants IAS to issue revised guidelines about the teaching of evolution. Clare will bring the new document before the membership for a vote at the Fall meeting. Changes will be put on the web site. Ed Frazier noted that the HASTI president wrote a letter, and they formally adopted the NSF guidelines for evolution teaching. Mike Foos suggested that the new document be edited by Jim Berry. The Council voted to bring the new document on teaching evolution to the membership to be voted on at the Fall meeting.

Youth Activities: No report.

Awards Committee: They asked for nomination for fellows and other Academy awards. The committee wants a curriculum vitae along with letters of nomination.

Biodiversity and Natural Areas Committee: About 30 or so people attended the mini-bioblitz at the St. Mary's meeting.

Junior Academy: No report.

Talent Search Committee: They need volunteers for judges.

Website: Marcia Moore is ill and could not attend the meeting. Newsletters are on now on the website.

Speaker of the Year: Uwe Hansen will find a speaker. Mike Lenan has accepted a stipend for this year's speaker, but there have been no requests for talks thus far.

Natural Resources Committee: There was a written report from Damian Schmelz since he was unable to attend the meeting.

Necrologist: Dr. Gommel noted that the following members have passed away—Duvall Jones, James A. Clark, and John Finney.

We need to update the e-mail addresses we have. E-mail addresses, especially those of government employees, often are not current.

Don Ruch moved that we approve a registration fee of $35 for the Fall Meeting to cover potential additional costs such as buses for members. Student registration fees should remain the same. It was approved.

Don Ruch inquired about the policy for students at the venue. It was decided that attendees will not get a program book if they do not register.

David Daniell said that we need to consider Fall breaks, etc. when accepting invitations from other schools, especially smaller institutions. Large schools can handle IAS meetings even if classes are in session.

The meeting adjourned at 4:05 PM.

THE EXECUTIVE COMMITTEE

Ball State University
2 November 2006

President Clare Chatot called the meeting to order at 1:43 pm EST. Others attending were: President-Elect John Schutt, Past-President Uwe Hansen, Treasurer Edward Frazier, Secretary Nils I. Johansen, Executive Director Nelson Shaffer, and Research Grants Committee Chair Jim Bandoli.

Minutes of the 21 April 2006 Spring Executive Committee Meeting at Ball State University were distributed and approved with corrections (motion by Uwe Hansen, seconded by Edward Frazier).

With a motion by John Schutt and seconded by Edward Frazier, there was approval of the agenda.

There was a presentation of Ian Hall of

WFYI TV 20 on the film on *The Natural Heritage of Indiana.* WFYI, a PBS station in Indianapolis, is looking for partners in developing and presenting a TV program series on the "Natural Heritage of Indiana" based on the book of the same name by past President of the Academy, Marion Jackson. A promotional DVD was shown to give a feel for the quality of the programs. Discussion of the film followed the presentation. A question was raised as to how this would benefit IAS and also about the cost of sponsorship. The consensus was that this would be a worthwhile project and needed to be pursued. There will be a discussion on funding sources and commitment at the December 2006 Budget meeting. The Budget Committee meeting will be on 9 December at 11 am (EST) at Butler University.

Old Business: With a motion by John Schutt and a second by Jim Bandoli, four new Fellows were approved. The new Fellows are Ekpo Ossom (University of Papua New Guinea), Charles Rhykerd (Purdue University), Jeffrey Hughes (Hanover College), and Thomas Simon (U.S. Fish and Wildlife Service).

A resolution thanking Ball State for hosting the meeting was read and unanimously approved for submission to the Council. The resolution will be read at the annual business meeting.

There was no new business.

The meeting adjourned at 2:35 pm (EST)

Respectfully submitted:
Nils I. Johansen, P.E.
Secretary

THE COUNCIL

Ball State University
2 November 2006

President Clare Chatot called the meeting to order at 2:45 pm EST. Those attending were: Clare Chatot (President), John Schutt (President-Elect), Uwe Hansen (Past-President), Edward Frazier (Treasurer), Nils I. Johansen (Secretary), Nelson Shaffer (Executive Director), Jim Bandoli (Research Grants Committee Chair), Brent Summers (AAAS representative), Marianna J. Zamlauski-Tucker (Chair, Zoology Section), Stanley Burden (Academy Foundation), Bill McKnight (Publications Committee), Frank A. Guthrie (Academy Foundation), William R. Gommel (Historian/Necrologist), John Langdon (Local Arrangements Committee), Ed Squiers (Past-President), Jim Berry (Editor of the *Proceedings*), Dan Webster (Past-President), Mike Foos (Nominations/Elections Committee), Donald G. Ruch (Newsletter Editor), Jennifer Metzler (Co-chair Youth Activities), Patty Zeck, Co-chair (Youth Activities), James R. Smith (Chair, Env. Quality Section), Kimberly Lyle-Ippolito (Chair, Cell Biology Section).

The minutes of the 21 April 2006 Spring Council Meeting at Ball State University were distributed and approved with corrections.

The agenda were presented and approved.

INDIVIDUAL REPORTS

Treasurer.—Ed Frazier handed out Financial Account summaries and explained the various entries.

Executive Director.—Nelson Shaffer handed out a report on the IAS membership, numbers and trends. He issued a plea for more members, both individual and institutional. A brief discussion ensued. Several ideas were presented as to how the membership could be increased: better interaction with the media, ask a friend to join, how to reach more of Indiana's scientists, recruit from new faculty members at our universities, work with the youth, how can IAS better help the high schools.

Editor of the *Proceedings*.—Jim Berry announced that the next issue of the *Proceedings* will contain the papers given at the Wabash River Symposium, as well a biography of Jim Gammon. Members were encouraged to recommend members to be honored with a biography in the *Proceedings.*

Newsletter editor.—Don Ruch reported that he needs information from the sections. The next President-Elect could work with him on this. Deadline for next issue is 15 November.

Secretary.—Nils Johansen thanked Nelson Shaffer for taking minutes at the last Spring meeting. Nils Johansen will get together with the new secretary (Heather Bruns) to assure a smooth transition.

President-Elect.—John Schutt will work with the Executive Director and the Executive Committee to try to find ways to increasing membership.

President.—Clare Chatot reminded the Council about the Technical Initiatives that the individual Sections can use as part of their meetings and encouraged them to take advantage of this opportunity. She also presented several information items to be presented at the Business Meeting.

A statement on the Teaching of Evolution in the Public Schools of Indiana will be presented at the Business Meeting for a vote by the membership. She also mentioned that WFYI (Indianapolis PBS) is working on a TV project on the "Natural Heritage of Indiana," and has approached IAS as a potential sponsor. Don Ruch strongly supported this.

Academy Foundation.—Frank Guthrie gave a summary of the financial status of the Academy and the individual accounts and the management of the accounts (Merrill Lynch) and also how the foundation interacts with and supports the operations of the Academy.

Research Grants.—Jim Bandoli reported on the awards of grants. For the Spring, there were 28 applications and 18 were approved. For the Fall, there were 18 applications, and the awards will be made shortly after the Fall meeting.

Programs and Invitations.—David Daniell was not present, but his written report was passed out. The 2007 meeting will be at the University of Indianapolis, with the Spring meeting on 13 April, with Field Trips on the 14th. The Fall meeting will be October 25 and 26. John Langdon at the University of Indianapolis will be the contact person. The 2008 meeting will be at the University of Evansville, and Dale Edwards is the contact person. No dates have been set. A 2009 meeting at Purdue is being considered.

Nominations.—Mike Foos reported on the results of the elections: Nils I. Johansen is the new President-Elect, Heather Bruns is the new Secretary, Joyce Cadwallader is the new member of the Research Grants Committee, and Wendell McBurney was re-elected to the Academy Foundation.

Publications.—Bill McKnight summarized the current activities of the committee and also problems at the State Library due to Oster's illness. He also noted that there will be a limited press run of the *Plants of the Chicago Region.*

Finance Committee.—Ed Squiers summarized its activities.

Youth Activities.—Patty Zeck and Jennifer Metzler gave an oral report emphasizing the importance of youth as future scientists and the outcomes of fairs and competitions. Nelson Shaffer reminded the Council of the opportunity for IAS members to be available as mentors to young people.

Library.—There was no report. Bill McKnight had covered the current status in his report on Publications.

Awards.—Clare Chatot announced the nominees for Fellow. The new Fellows are Ekpo Ossom (University of Papua New Guinea), Charles Rhykerd (Purdue University), Jeffrey Hughes (Hanover College), and Thomas Simon (U.S. Fish and Wildlife Service). These names will be officially accepted at the Business meeting. Dr. Chatot also encouraged the membership to nominate deserving members for Fellow or other appropriate awards. The web-site has details, forms, etc.

Biodiversity.—Don Ruch said that Biodiversity is an independent agency now. Upcoming meetings will focus on the possible "Bio-blitz" next summer.

Web-site.—Marcia Moore was not present, but she left word that there will be a transition from Butler University as location of the server to a new group. Other commercial agencies are now available at reasonable prices so we do not have to rely on Butler to support our web-site. Marcia Moore will continue as webmaster.

Speaker of the Year.—Uwe Hansen would like to have life science input as to possible speakers and asked members with suggestions to contact him.

Natural Resources Commission.—Damien Schmelz was unable to attend, but his written report was distributed.

Representative to AAAS.—Brent Summer gave an oral report.

Historian/Necrologist.—Bill Gommel announced the passing of the following members over the last year: John K. Bouseman (Indiana Natural History Survey), James A. Clark (Cicero, IN), John C. Finney (Anderson, IN), Duvall A. Jones (St. Joseph's College, and President of the Academy in 1993), Benjamin Moulton (Indiana State University, and President of the Academy in 1985). The list will also be read at the Business meeting and honored by a minute of silence.

Local Arrangements.—Don Ruch summarized the upcoming activities. Clare Chatot expressed her appreciation to Don Ruch for his work in preparing for the meeting.

Budget Meeting.—The budget meeting (for the 2007 budget) will be at Butler University on 9 December at 11 AM (EST). Budget items should be sent to Ed Frazier.

Resolution.—A resolution thanking Ball State University for hosting the meeting was read and unanimously approved. It will be read at the Business meeting.

New Business.—The proposal from WFYI was discussed earlier and the demo DVD played. Ed Frazier made the motion, seconded by Uwe Hansen, that the Council goes on record as supporting financially this video production. It was approved unanimously.

Adjourn.—The meeting was adjourned at 5:08 PM (EST).

Respectfully submitted:
Nils I. Johansen, P.E.
Secretary

2007. Proceedings of the Indiana Academy of Science 116(1):115

INDIANA ACADEMY OF SCIENCE
2006 Year End Financial Report

	Balance 1-Jan-06	Revenues	Expenses	Balance 31-Dec-06
OPERATING FUND				
Dues		23,225.00		
Interest		1,592.05		
Contributions		50.00		
Spring Meeting		200.00	240.44	
Annual Meeting		8,060.00	6,798.25	
Misc. Income		4.36		
Officer's Expenses			4,300.00	
Operating Expenses			4,900.05	
Financial Expenses			2,501.92	
Newsletter Expenses			1,734.12	
Library Operations			0.00	
Committee Expenses			0.00	
Speaker of the Year			700.00	
AAAS Representative			377.53	
Web Site Development			2,000.00	
Youth Activities			0.00	
Operating Fund Total	13,212.37	33,131.41	23,552.31	22,791.47
RESTRICTED FUNDS				
Proceedings	9,791.13	23,527.25	19,793.14	13,525.24
Publications	15,699.30	5,281.81	9,157.21	11,823.90
* Research Grants	15,963.49	81,181.94	81,931.94	15,213.49
Indiana Biological Survey	(515.58)	515.58	0.00	0.00
Lilly Library	6,578.44	0.00	0.00	6,578.44
Welch Fund	8,674.50	189.97	0.00	8,864.47
Life Members Fund	6,295.25	2,500.00	0.00	8,795.25
Past Presidents Fund	8,778.39	0.00	200.00	8,578.39
Total Restricted Funds	71,264.92	113,196.55	111,082.29	73,379.18
Prepaid Dues	5,130.00	5,395.00	5,130.00	5,395.00
TOTAL FUNDS	**89,607.29**	**146,327.96**	**134,634.60**	**101,565.65**
FUNDS ON DEPOSIT				
Checking Account	3,097.52	134,444.54	134,488.47	3,053.59
Money Market Savings	74,961.09	86,812.32	75,000.00	86,773.41
Cert. of Deposit	11,548.68	189.97	0.00	11,738.65
TOTAL FUNDS DEPOSITED	**89,607.29**	**221,446.83**	**209,488.47**	**101,565.65**

* Provided 29 senior member grants and 23 high school grants.

	Balance 1-Jan-06			Balance 31-Dec-06
ACADEMY FOUNDATION FUNDS				
John S. Wright Fund Account	6,502,663.84			4,722,360.16
PIA Account				2,291,000.00
Academy Fund Account	242,560.75			247,246.03
Invested Income Account	495,283.84			597,376.59
TOTAL FOUNDATION FUNDS	**7,240,508.43**			**7,857,982.78**

Foundation Funded Used For:	
Proceedings	13,459.25
Research Grants	77,579.14
Total	91,038.39

Edward L. Frazier
Treasurer

Audited April 7, 2007

INSTRUCTIONS TO AUTHORS

(revised May 2007)

General information.—Manuscripts and all correspondence should be sent to the Editor. To be eligible for publication in the *Proceedings*, at least one author must be a member of the Academy. There are two categories of papers: regular feature articles (usually longer than three pages) and short communications (three pages or less). Submission of a manuscript to the Editor implies that it has not been sent to another publication, nor has it been published elsewhere. If it is accepted for publication in the Proceedings, it may not be republished without the written consent of the Academy.

All manuscripts are evaluated by referees. Submit three copies of the manuscript. Figures in manuscripts for review may be submitted as photocopies, and they should be approximately the size that they will be printed in the *Proceedings*.

After the manuscript has been accepted, the author will be asked to submit the manuscript as a paper copy and on a computer disc in a widely-used word processing program. Indicate clearly on the computer disc the **word processing program** and the **type of computer** (Mac or PC).

Galley proofs will be sent to the primary author for approval and correction.

Voucher specimens and permits: Voucher specimens of species used in scientific research should be deposited in a recognized scientific institution. Authors must indicate that the collection of specimens, especially of threatened or endangered species, was authorized by the appropriate governmental organizations. All type specimens must be deposited in a recognized museum collection.

Style.—Do not use right or full justification. Also, use a non-proportional font (e.g, Courier, but not Times Roman).

Title page.—The title page should include (1) the title in capital letters, (2) each author's name and address, (3) the running head (see below), and (4) the complete name, address, and telephone number of the author with whom proofs and correspondence should be exchanged, a FAX number and electronic mail address if available.

Abstract.—All manuscripts have an abstract, which should summarize the significant facts in the manuscript. The "ABSTRACT" heading in capital letters should be placed at the beginning of the first paragraph set off by a period. Use complete sentences, and limit the abstract to one paragraph and 250 words.

Keywords.—Give 3–5 appropriate keywords following the abstract.

Text.—Double-space text, tables, legends, etc. throughout. Three categories of headings are used. The first category (METHODS, RESULTS, etc.) is typed in capitals, centered, and on a separate line. The second (lower) category of heading, in bold type, begins a paragraph with an indent and is separated from the text by a period and a dash.(This paragraph begins with an example of this heading.) The third heading category may or may not begin a paragraph, is italicized and followed by a colon. (The paragraph below is an example.) Use only the metric system unless quoting text or referencing collection data.

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Walter, J. 1992. The significance and complexity of communication in moths. Pp. 25–66, *In* Insect Communications: Mechanisms and Ecological Significance. (P.N. Work & J.S. Rivers, eds.). Princeton University Press, Princeton, New Jersey.

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Figures 1–4.—Right chelicerae of species of *Centruroides* from Timbuktu. 1. Dorsal view; 2. Prolateral view of moveable finger; 3. *Centruroides* holotype male; 4. *Centruroides* male. Scale = 1.0 mm.

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